ENERGY CONSERVATION IN THE INDUSTRIAL MINERAL SECTOR
– COMMINUTION –

Prepared for:

Canada Center for Mineral and Energy Technology (CANMET)

Energy, Mines and Resources Canada

Volume II

Asbestos
Cement
Gypsum
Lime
Limestone

CANADA CEMENT LAFARGE LTD.
MONTREAL, CANADA

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VOLUME II

Asbestos
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CONTENTS OF VOLUME II

Industry Reviews

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THE ASBESTOS INDUSTRY

ENERGY CONSERVATION IN THE INDUSTRIAL MINERALS PROCESSING SECTOR - COMMINUTION

(Phase I - Plant Studies)

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2. Product Characteristics
3. Quality Criteria

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1. INTRODUCTION

Cooperating Company:

Lac d'Amiante du Québec Ltée (L.A.Q.)

Plant Location:

Black Lake, Quebec

The report first introduces the cooperating company. A description follows of the comminution processes monitored during the field work at the company's plant. The measurements made and results obtained are then reported, discussed and concluded.

For readers who are not familiar with the Asbestos industry, an appendix entitled "Industry Review" has been added.

Details concerning data collection and field work, as well as other raw data, are available in the working papers.

2. COMPANY DESCRIPTION

Lac d'Amiante du Québec Ltée, (LAQ) was originally known as Lake Asbestos of Quebec Ltd. It was formed in 1952 as a subsidiary of ASARCO Inc., a leading international non-ferrous mining, smelting and refining company.

2.1 General

The company's ore bodies lay under a lake located near the town of Black Lake, Quebec, approximately 113 km southwest of Quebec City. The Crown granted mining rights in 1948 to United Asbestos Corporation Ltd., who conducted the initial exploration program.

The exploratory results were presented to LAQ, which decided to investigate the property further. In 1954, a final agreement between LAQ and United Asbestos was reached; the property would be developed on a profit-sharing basis.

The company re-routed a river, a major highway and a railroad. Then drained the lake, built basins and dams, and removed more than 55 million cubic meters of earth to reach the asbestos ore at the bottom of the 4km-long lake.

LAQ acquired another mine, The National, in 1973. The mine and mill, located near Robertsonville, Quebec, were in operation when purchased.

The LAQ operation employs 750 people; 650 union hourly and 100 staff, working 3 shifts per day six days per week to mine 50,000 tonnes of ore per day.

In Canada, the company is currently second in finished product capacity and third in the amount of ore mined.

The estimated future life of the quarry is 20 years, which would require that the mine be deepened another 90 meters.

2.2 Products

The LAQ milling operation at Black Lake, Québec, produces 50 or more different product grades. Additional grades can be produced, as the primary difference between grades is fiber length distribution. Other important characteristics are degree of openness, cleanliness and strength. Consumers demand uniformity of the product, which is controlled during fibre production. Tests are made on samples taken at frequent intervals in the fibre circuit. As the results are analysed, adjustments to the grading circuit may be made.

Normally, the fibre is contained in bins before being fed into the packing machines. A sample of each bag and a composite sample per tonne of product are tested to ensure the quality of the final shipment.

The Quebec asbestos industry classifies milled asbestos fibres into 5 main groups according to fibre length distribution. These are numbered 3, 4, 5, 6 and 7, with the longest fibres in group 3. Each group is divided into subgroups or grades identified by the letters A to Z, with 'A' denoting the longest fibre of the group. At LAQ, fibre is further classified by degree of fiberization or "openness", according to the degree the fibres or "pencils" have been separated into smaller bundles. Two or three degrees of openness are available in most grades. Although fibres may be the same length, openness can make a great difference in both product processing and physical properties. For example, more open fibres have a greater surface area.

At LAQ, the grades marketed are shown in Table 1.

TABLE 1 - LAQ Fibre Grades

A STANDARD DESIGNATION OF GRADE	B GUARANTEED MINIMUM TEST				C CURRENT LAQ CLASSIFICATION		
3F	10.5	-3.9	-1.3	-0.3	---	3F4	---
3K	7	-7	-1½	-½	3K3	3K4	---
3R	4	-7	-4	-1	3R3	3R4	---
3T	2	-8	-4	-2	3T3	3T4	---
3Z	1	-9	-4	-2	3Z3	3Z4	---
4A	0	-8	-6	-2	4A3	4A4	---
4D	0	-7	-6	-3	4D2	4D4	---
4K	0	-4	-9	-3	4K3	4K4	---
4M	0	-4	-8	-3	---	4M4	---
4T	0	-2	-10	-4	4T3	4T4	4T5
5D	0	-½	-10½	-5	5D3	5D4	5D5
5K	0	-0	-12	-4	5K3	5K4	---
5M	0	-0	-11	-5	5M3	5M4	---
5R	0	-0	-10	-6	5R3	5R4	---
5Z	0	-0	-8.6	-7.4	---	---	---
6D	0	-0	-7	-9	6D3	6D4	6D5
7D	0	-0	-5	-11	7D3	7D4	7D5
7F	0	-0	-4	-12	---	7F4	---
7H	0	-0	-3	-13	7H2	7H3	7H4
7K	0	-0	-2	-14	---	7K4	---
7M	0	-0	-1	-15	7M2	7M4	7M5
7R	0	-0	-0	-16	7R2	7R4	7R5
7T	0	-0	-0	-16	7T2	7T4	7T5

COLUMN A	indicates standard groups and grades.
COLUMN B	indicates minimum number of ounces retained on four Quebec standard screens for each grade.
COLUMN C	lists specific grades available from LAQ and degree to which fibre has been processed or opened. The third digit indicates openness. Example: 4T3 least open, 4T4 medium open, 4T5 most open.

An approximate breakdown of production at LAQ by grade is:

Grade 3 - 2%
" 4 - 50%
" 5 - 15-20%
" 6 - 15%
" 7 - 18%

The products are compressed into cakes and packaged in 3-ply paper or woven polyethylene bags. The standard unit has been pressure reduced from 0.3m^3 of bulk material to 0.06m^3, weighing 50 kilos.

The pressure packed fibre is shipped on pallets or cardboard slipsheets in one or two tonne lots. If requested, the lots can be stretch-wrapped in plastic, which stabilizes the load and prevents damage to the bags in transit.

Shipments in North America are made by rail and truck. A rail freight carload is betweem 45 to 55 tonnes. Shipments sent overseas are transported in standard containers from St. Lawrence River or from Atlantic Coast ports.

3. PROCESS DESCRIPTION

3.1 Process Flow

A review of the LAQ asbestos operations is illustrated in Figure I, Rock Processing and Figure II, Fibre Grading.

The rock processing phase is made up of three circuits; Crushing, Drying and Milling. Comminution is confined to the crushing and drying circuits. It is indirectly associated with the mill rock line and fibre grading.

Asbestos manufacturing is different from other industrial minerals because only a small percentage (18%) of the rock mined is actually milled and the comminution process "releases" the mineral from the host rock.

3.2 Crushing

After mining, the primary rock processing operation is crushing, which is detailed in Figure III. The equipment is listed in Table 2.

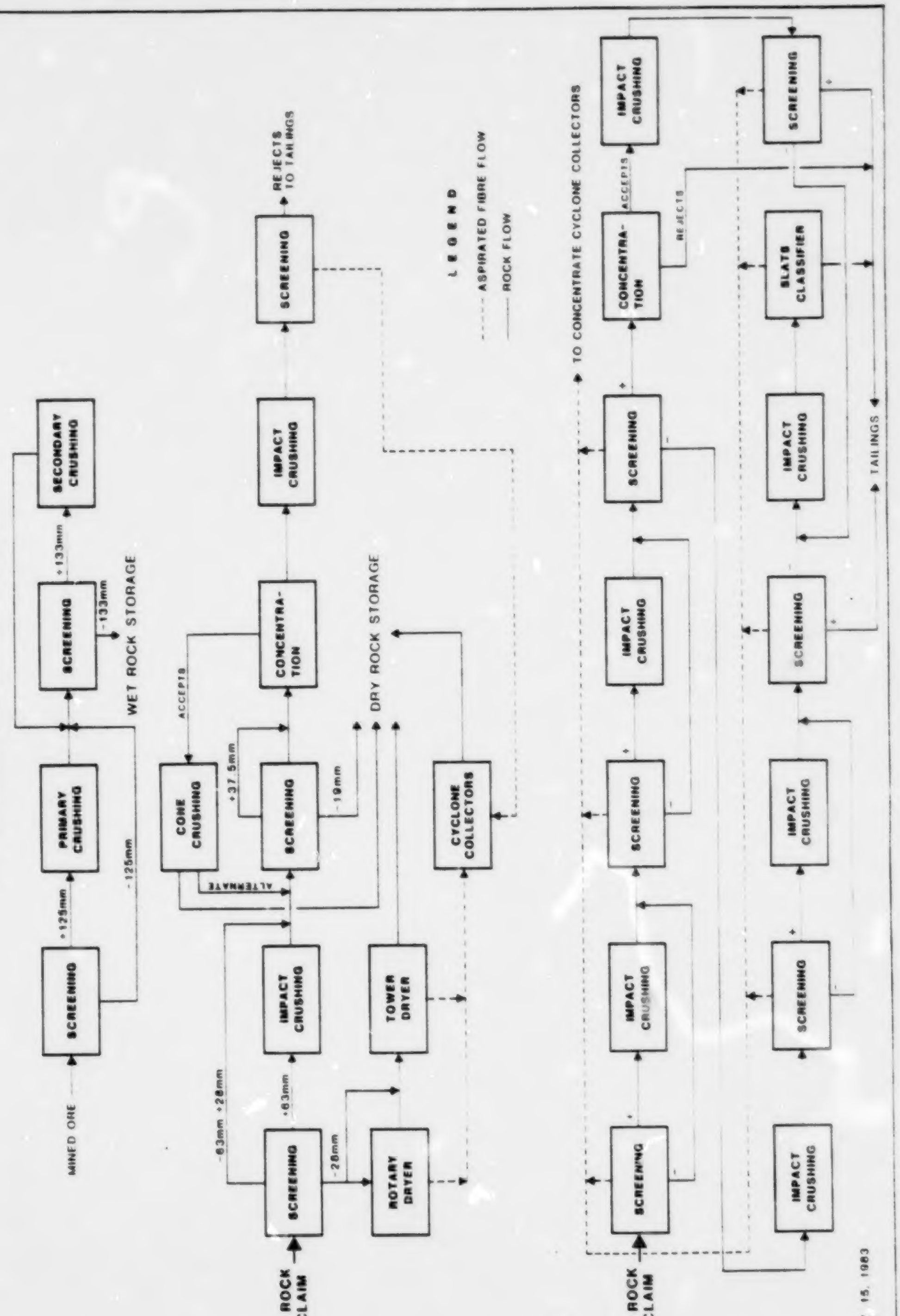
Ore is transported to the primary crusher in 45 or 91 tonne truckloads. It is discharged onto an apron feeder and flows down across the 125 mm operator controlled grizzly to the primary crusher.

The grizzly undersize (-125 mm) material by-passes the primary crusher and feeds two 133 mm Ty-Rock F800 screens which operate in parallel.

Figure I – ASBESTOS

PROCESS FLOW SHEET – ROCK PROCESSING

LAC D'AMIANTE, BLACK LAKE, QUEBEC



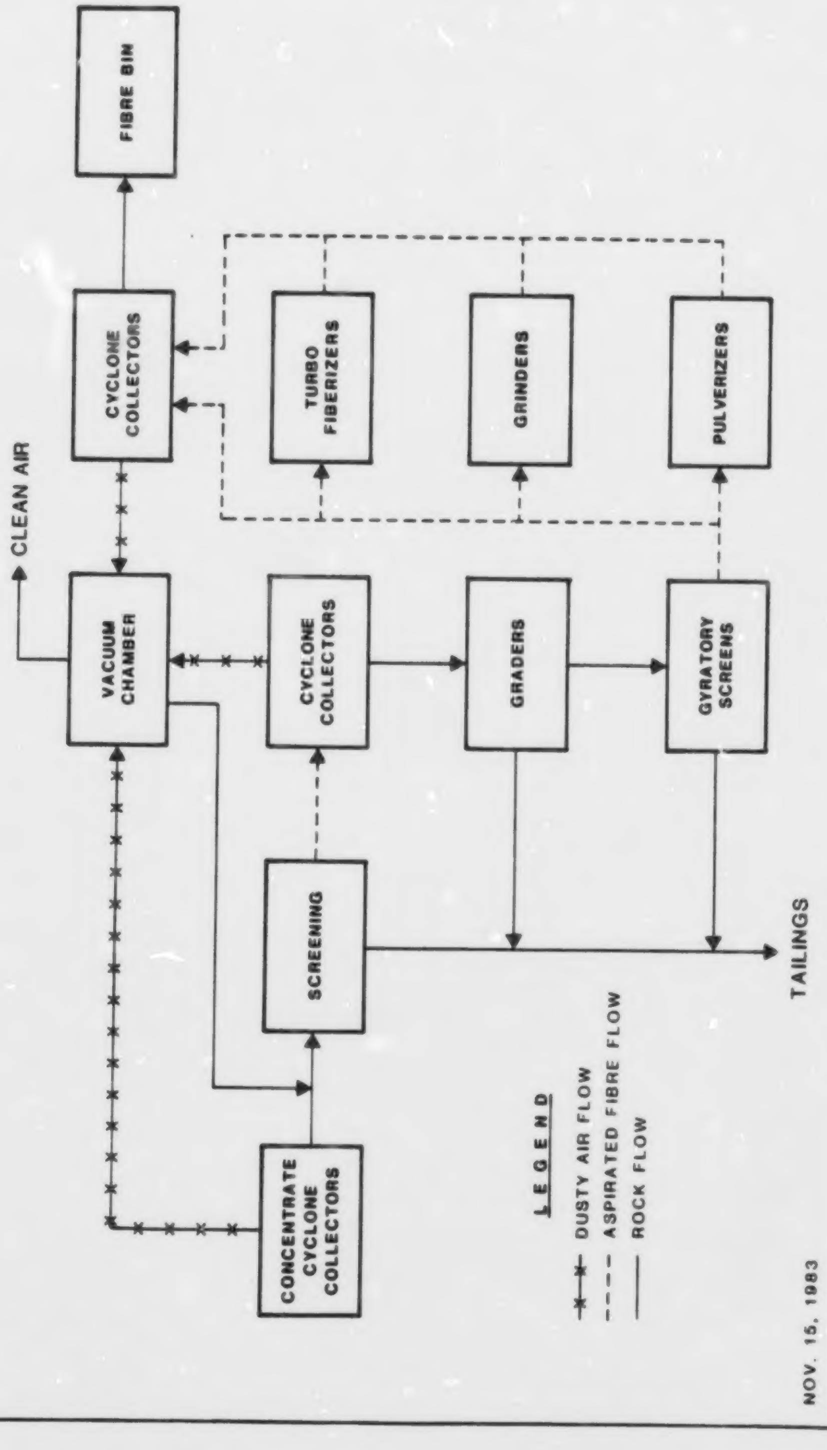


Figure II – ASBESTOS
PROCESS FLOW SHEET – FIBRE GRADING
LAC D'AMIANTE, BLACK LAKE, QUEBEC

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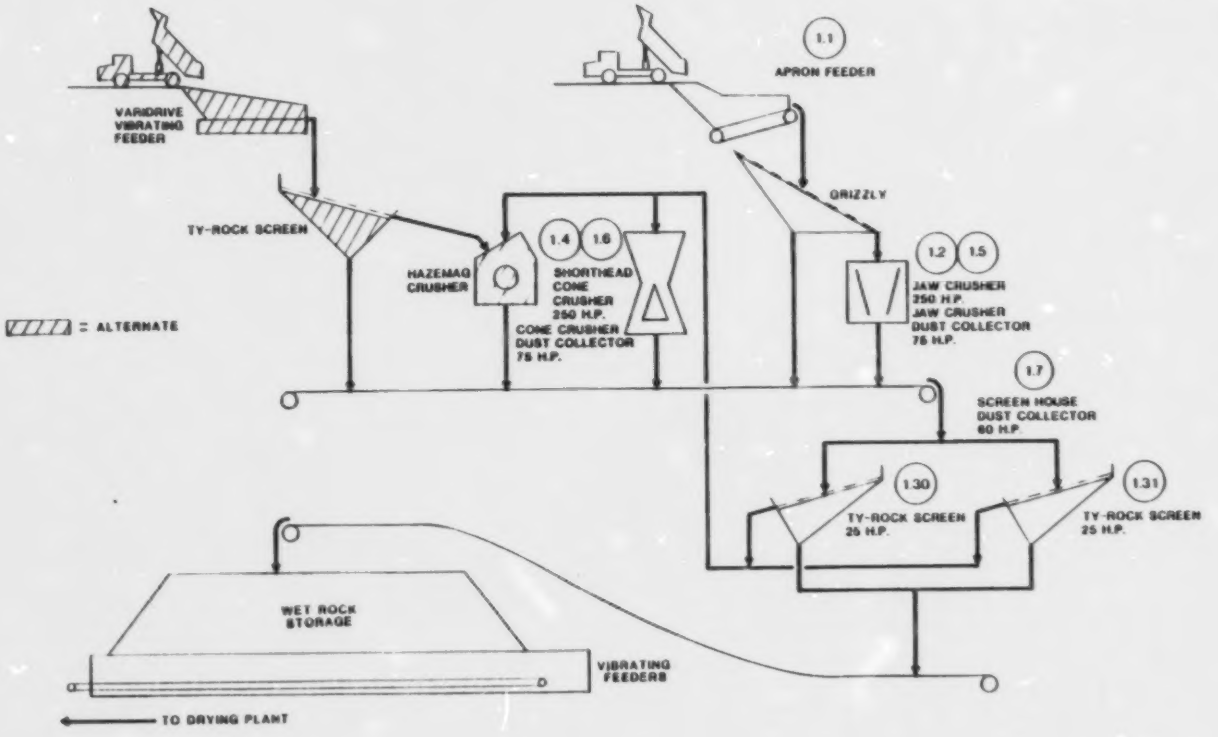

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FIGURE III
CRUSHING CIRCUIT
FLOW DIAGRAM

PLANT No LAC D'AMIANT
BLACK LAKE, QUEB

PROJECT No. 20010

TABLE 2 - Crushing Circuit Equipment List

EQUIPMENT		MOTOR*	
No.	TYPE/MAKE/MODEL	HP	AMPS
1.1	Apron Feeder	25/16.7	23.8/16.8
1.2	Jaw Crusher - Traylor (4160V)	250	33
1.3	Ty-Rock Screen - F800	25	25
1.31	Ty-Rock Screen - F800	25	25
1.4	Symons 7ft Cone Crusher (4160V)	250	33
1.5	Jaw Crusher Dust Collector (19,950 CFM)	75	71-75
1.6	Cone Crusher Dust Collector (19,950 CFM)	75	71-75
1.7	Screen House Dust Collector (19,950 CFM)	60	60
2.1	Varidrive Vibrating Feeder	40/27	37/29
2.2	Ty-Rock Screen - F900	45	25
2.3	Hazemag Crusher - N500 (4160V)	450	60
2.4	Hazemag Crusher Dust Collector (22,800 CFM)	100	96

* All motors 550 volt unless noted.

The screens (1.3, 1.31) operate in closed circuit with the secondary cone crusher (1.4) processing the oversize and rescreening the crusher discharge. The undersize (-133 mm) is then conveyed to the wet rock storage area.

The wet rock storage area has a capacity of 136,000 tonnes and is advantageous because:

- it will supply ore to the mill if a serious breakdown in the crushing or screening circuit occurs,
- it facilitates blending of the ore coming from different parts of the ore body,
- it ensures a constant feed to the dryers, eliminating any variation of ore from the mine.

Also, there is an alternate primary system consisting of a variable drive vibrating feeder, a F900 Ty-Rock screen (2.2) and a N500 Hazemag crusher (2.3). Individually, the Hazemag crusher may be used as an alternate secondary crusher or to assist the cone crusher should the feed rate be excessive.

3.3 Drying

Drying is detailed in Figure IV. The associated equipment is listed in Table 3.

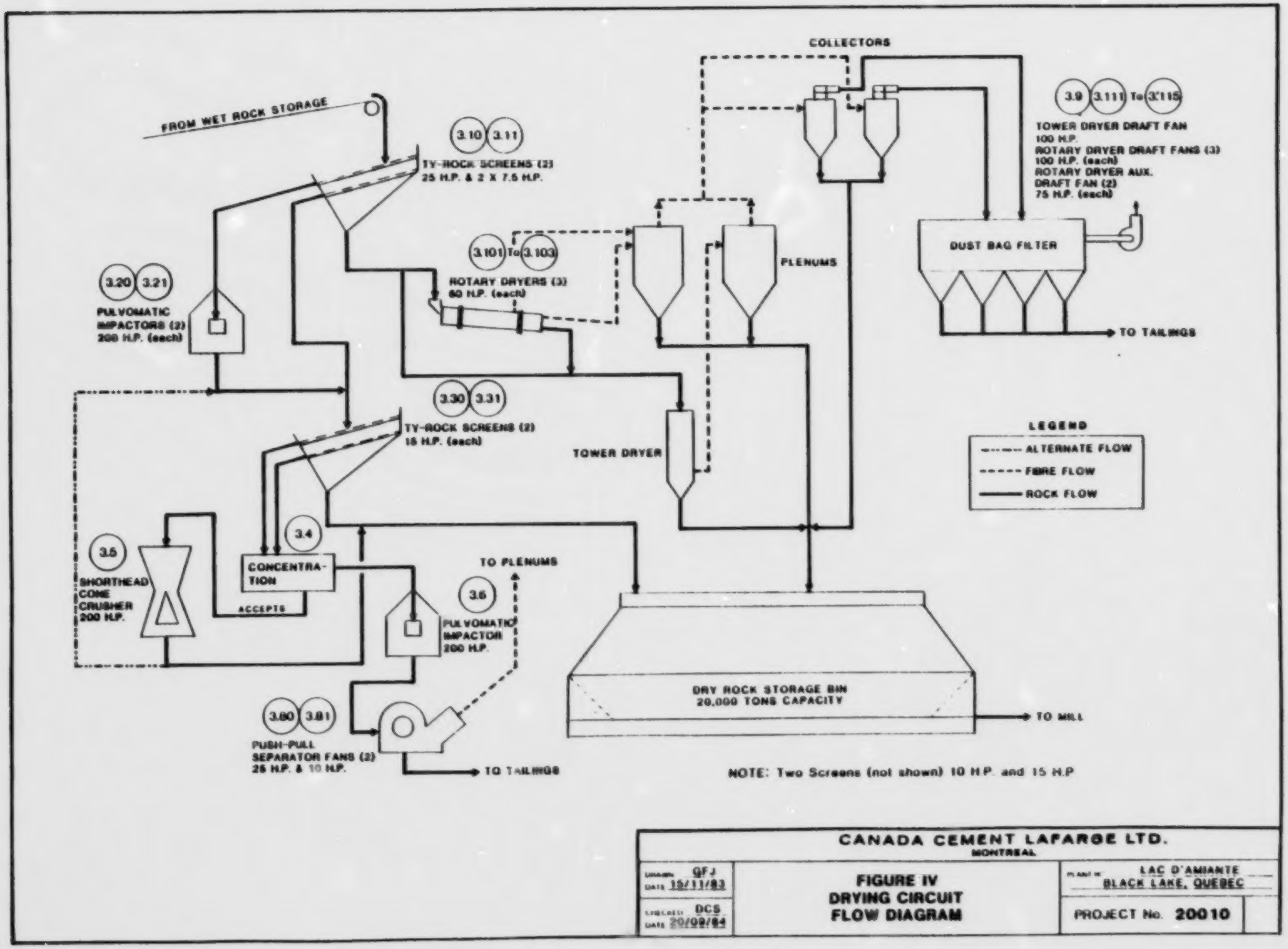
Efficient fibre separation requires that the ore be dry. Depending upon the season and weather conditions, the feed will have a moisture content of between 4 and 10 percent, which must be reduced to between 1.2 and 0.8 percent. Nominally, the feed rate is 700 tonnes per hour.

Vibrating feeders retrieve the rock and discharge it on to a belt conveyor that transports it to two F600 Ty-Rock double-deck vibrating screens (3.1, 3.11).

From screening, the undersize (-28 mm) is fed to the rotary or tower dryers (3.101, 3.103) and on to dry rock storage. The dust and asbestos fibers are removed by the aspiration air flow to the plenum and cyclone collectors, processed and directed to dry rock storage.

The middle cut and oversize, by-pass the dryers. The middle cut flows directly to a second set of Ty-Rock screens (3.3, 3.31) joining the oversize which must first be crushed in the impact crushers (3.2, 3.21).

After screening, the undersize (-19 mm) passes directly to dry rock storage. The middle cut and oversize (+37.5 mm) are sent to concentration (3.4). The accepts proceed to the cone crusher (3.5) and on to dry rock storage. The rejects are directed to a Pulvomatic impactor (3.6), and on to screens (3.7, 3.71) and air separation (3.8, 3.81), with the non-aspirated material going to tailings.



NOTE: Two Screens (not shown) 10 H.P. and 15 H.P

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FIGURE IV
DRYING CIRCUIT
FLOW DIAGRAM

PLANT N° LAC D'AMIANTE
BLACK LAKE, QUEBEC
PROJECT No. 20010

TABLE 3 - Drying Circuit Equipment List

EQUIPMENT		MOTOR*	
NO.	TYPE/MAKE/MODEL	HP	AMPS
3.1	Ty-Rock Screen - F600	25	26
3.11	Ty-Rock Screen - F600	2 x 7.5	7.6
3.2	Pulvomatic Impactor	200	198
3.21	Pulvomatic Impactor	200	198
3.3	Ty-Rock - F600	15	15
3.31	Ty-Rock - F600	15	15
3.4	Concentration	-	-
	Sterns Drum Drive	-	-
	Sterns Drum Magnet	-	-
	Sterns Drum Drive	-	-
	Sterns Drum Magnet	-	-
3.5	5.5' Short Head Cone Crusher (4160V)	200	29
3.6	Pulvomatic Impactor - 42"	200	198
3.7	Screen	10	11
3.71	Screen	15	15
3.8	Push Pull Separator Fan	25	25
3.81	Push Pull Separator Fan	10	10
3.9	Tower Dryer Draft Fan	100	96
3.101	Rotary Dryer Drive #2	60	58
3.102	Rotary Dryer Drive #3	60	58
3.103	Rotary Dryer Drive #4	60	58
3.111	Rotary Dryer Draft Fan	100	96
3.112	Rotary Dryer Draft Fan	100	96
3.113	Rotary Dryer Draft Fan	100	96
3.114	Rotary Dryer Auxiliary Draft Fan	75	72
3.115	Rotary Dryer Auxiliary Draft Fan	75	72

* All motors 550 volt unless noted

3.4 Milling Circuit

Detailed in Figure V is the Milling Circuit. The equipment list is shown in Table 4.

The milling circuit flowrate averages about 8,200 tonnes of ore per day, of which, 3% to 6% is fibre. Thus, the fibre production rate is about 500 tonnes per day.

The milling process has the following functions:

- to reject barren rock at the earliest stage possible,
- to recover the maximum amount of fibre without affecting fibre length or degree of openness,
- to remove residual rock particles,
- to separate the fibre to the required degree of openness and remove fine grit and dust trapped in the fibre,
- to grade the fibre to the required standard classified lengths,
- to package the finished product.

Also, the system must have an effective air handling operation to transport and separate the fibre and to control dust.

There is no standard method of milling asbestos. Each technique is designed to suit the ore from a particular deposit, while maintaining flexibility. However, the basic operations of crushing, drying, fibre separation, cleaning, fiberizing, grading and packaging are common to all mills.

The asbestos fibre is aspirated as it is released everywhere in the circuit. This protects the openness of the fibre and minimizes the absorption of fine dust.

The dry rock storage feed is discharged into a distribution bin which feeds a battery of double-deck vibrating screens (4.1, 4.11, 4.12). The oversize feeds two Torrey Impactors (4.2, 4.21) whose discharge comnbines with the screened undersize to feed the next set of screens (4.3, 4.31), where the process is repeated to feed screens (4.5, 4.51).

At this point, the process divides. The oversize from the top deck of the tandem screens (4.5, 4.51) proceeds to concentration to remove the iron bearing rock. The accepts continue on to a JM fiberizer (4.110) whose discharge forms the feed to screen (4.12).

The oversize from the second deck of the tandem screens (4.5, 4.51) feeds a Denovan Impactor (4.6) and the discharge combines with the screen undersize to feed screens (4.7, 4.71).

The oversize of (4.7, 4.71) is fiberized in a JM fiberizer (4.8) whose discharge and the screens undersize form the feed for screens (4.9, 4.91).

Some consolidation now takes place, with the oversize of screens (4.9, 4.91 and 4.120) being discharged to tailings and the undersize combining to feed a Denovan Impactor (4.130).

The discharge of the Denovan Impactor (4.130) is conveyed to a slats classifier, where the remaining fibre product is drawn off and the refuse discharged to tailings.

As shown, at each screening or classification step, fibre product is removed by the draft air flow to the concentrate collectors and vacuum chamber.

TABLE 4 - Mill Rock Line Equipment List 3

EQUIPMENT		MOTOR*	
No.	TYPE/MAKE/MODEL	HP	AMPS
4.1	Screen	7.5	7.6
4.11	Screen	10	11
4.12	Screen	10	11
4.2	Torrey Impactor	75	70
4.21	Torrey Impactor	75	76
4.3	Screen	7.5	7.6
4.31	Screen	7.5	7.6
4.4	Torrey Impactor	75	72
4.41	Torrey Impactor	75	72
4.5	Screen	7.5	7.8
4.51	Screen	7.5	7.8
4.6	Denovan Impactor	150	138
4.7	Screen	5	5.1
4.71	Screen	5	5.1
4.8	JM Fiberizer	125	119
4.9	Screen	5	5.1
4.91	Screen	5	5.1
4.100	Concentration	-	-
4.101	Concentration	-	-
4.110	JM Fiberizer	150	136
4.120	Screen	5	5.1
4.130	Denovan Impactor	75	72

* All motors 550 Volt capacity, unless noted.

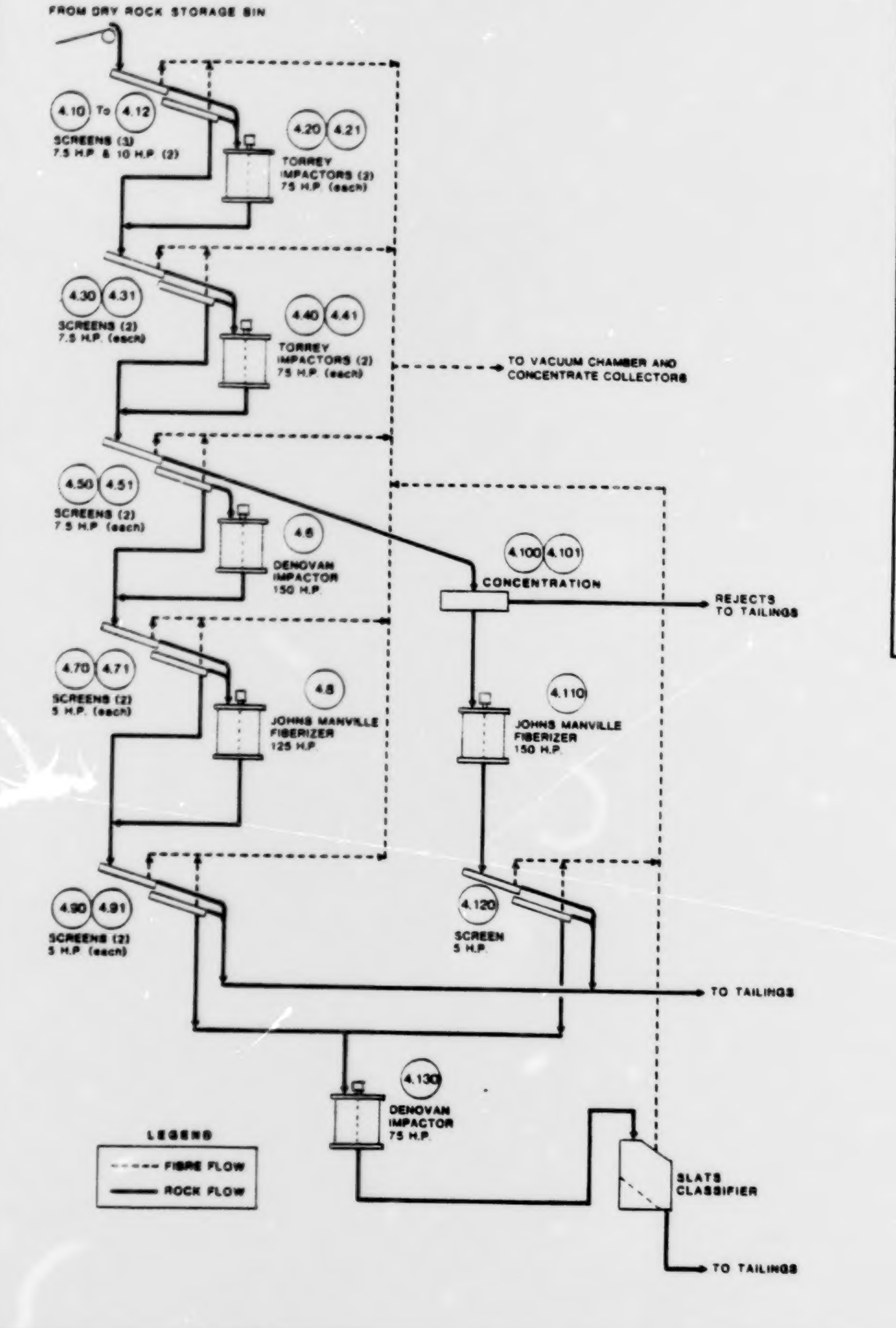

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FIGURE V
MILLING CIRCUIT
FLOW DIAGRAM

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BLACK LAKE, QUEBEC

PROJECT No 20010

3.5 Fibre Grading

Fibre grading, or the product line process, is detailed in Figure VI and the equipment is listed in Table 5.

Various concentrations of fibre are fed to tandem shaking screens (5.2) for further refinement. The aspirated fibre is segregated and concentrated again in cyclone collectors. The residual material goes to tailings.

The collectors feed a dust grader (5.3), further refining the product, and the discharge feeds gyratory screens (5.4, 5.41), for the final refining step. Next, the fibre is prepared to specification through the use of specialized equipment such as Turbo fiberizers (5.5, 5.51), a grinder (5.6), or a Hurricane pulverizer (5.7).

As shown in Figure VI, screening provides a means of preparing the fibre for aspiration. The "crushing" is used only to release the fibre from the rock, not to reduce the size of the material as in a normal comminution operation.

The fibrous material is vacuumed to the concentrate collectors where the fibres are then discharged to the cleaning, grading and fiberizing circuits. The asbestos dust is filtered out in the vacuum chamber and returned for reprocessing.

3.6 Packaging and Shipping

From the fibre bins, blends are packaged in bags of 3-ply paper or woven polyethylene. The operation is completely automatic, including palletizing. For security and weather protection, one or two tonne shipments can be stretch-wrapped in a strong polyethylene film.

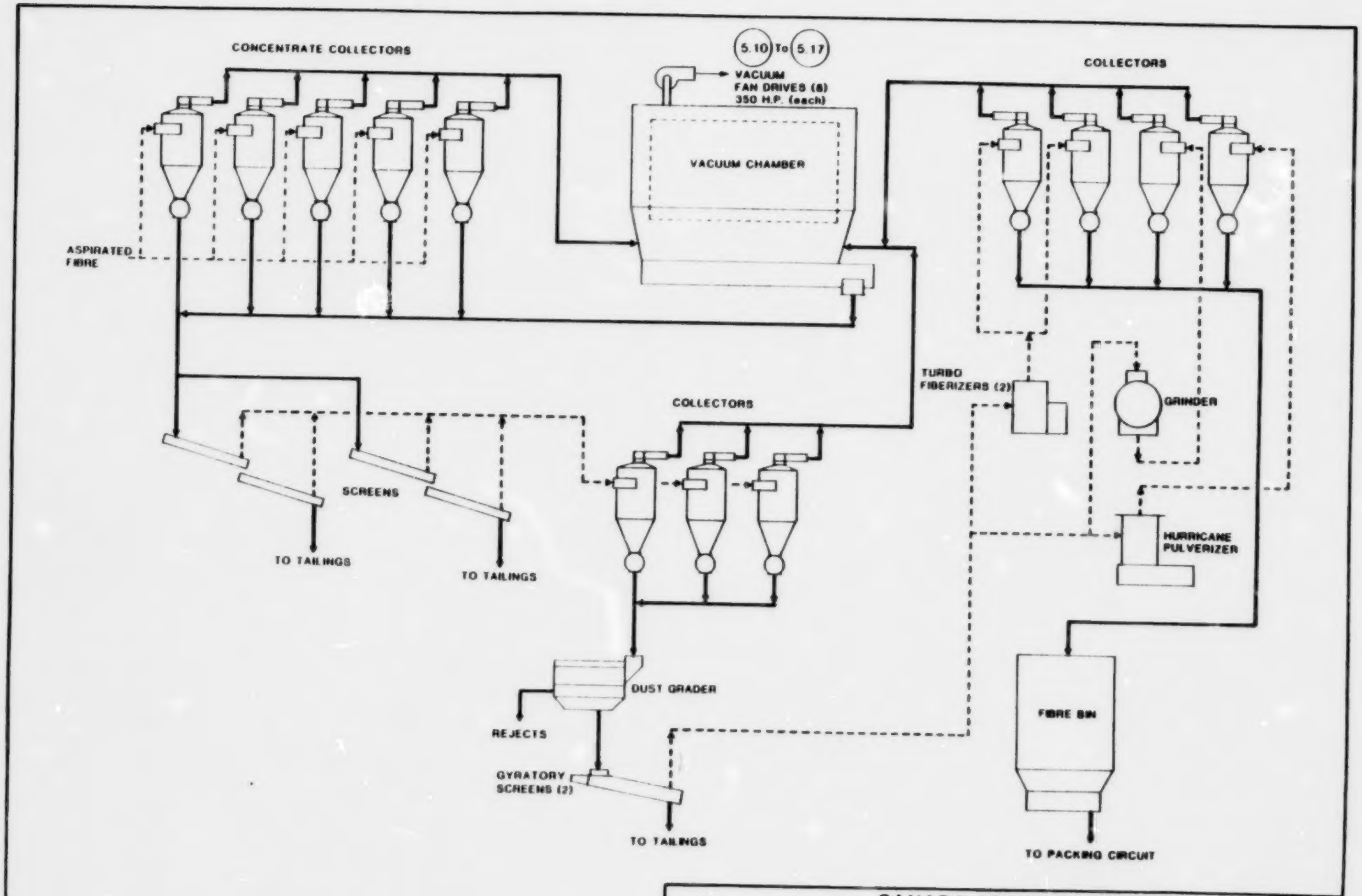

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FIGURE VI
ASPIRATION AND GRADING CIRCUIT
FLOW DIAGRAM

PLANT N LAC D'AMIANTE
BLACK LAKE, QUEBEC

PROJECT No 20010

TABLE 5 - Cleaning, Grading and Fiberizing Circuit Equipment List 4

EQUIPMENT		MOTOR*	
No.	TYPE/MAKE/MODEL	HP	AMPS
5.1	Vacuum Fan Drive #1	350	46
5.11	Vacuum Fan Drive #2	350	46
5.12	Vacuum Fan Drive #3	350	46
5.13	Vacuum Fan Drive #4	350	46
5.14	Vacuum Fan Drive #5	350	46
5.15	Vacuum Fan Drive #6	350	46
5.16	Vacuum Fan Drive #7	350	46
5.17	Vacuum Fan Drive #8	350	47
5.2	Screens		
5.3	Dust Grader	25	26.5
5.4	Gyratory Screen		
5.41	Gyratory Screen		
5.5	Turbo Fiberizer	50	50
5.51	Turbo Fiberizer	40	39
5.6	Grinder	50	46
5.7	Hurricane Pulverizer	125	114

* Vacuum Fan Drives are 4160 Volt capacity, all others are 550 Volts.

3.7 Air Handling System

The production of asbestos requires large quantities of air, which, by the pull-through method, circulates rapidly through the fibre processing and dust control systems. The vacuum chamber, in the milling circuit, passes 336,000 m^3/minute of air through approximately 21,000 polyester filter bags. In addition, each of the other circuits have their own dust collection and vacuum systems.

In the main vacuum chamber, an ambient particulate monitor (APM) is used to measure the amount of respirable dust in the filtered air. The information is used to monitor the quality of air recycled into the mill and to indicate the chamber's operating efficiency.

3.8 Quality Control

To meet rigid consumer specifications, the asbestos industry uses extensive quality control procedures throughout production.

Normally, a small sample from each bag is taken to form a lot and shift composite sample. These are evaluated in accordance with the various Quebec Asbestos Mining Association (QAMA) test methods, to determine the dry and wet screen length distribution, degree of fiberization, grit content, surface area, bulk color, filtration, absorption and asbestos-cement strength.

Table 6 lists the QAMA's standard tests. Detailed procedures are described in the Association's Chrysotile Asbestos Test Manual.

TABLE 6 - QAMA Standard Tests

FIBRE LENGTH TESTS

1. Quebec standard screen
2. Ro-Tap screen
3. Bauer-McNett screen
4. Suter Webb comb
5. Wash test for 200 mesh fines

FIBRE OPENNESS TESTS

1. Wet volume or buoyancy
2. Loose density or dry bulk
3. Surface area by air permeability
4. Crudy or grit content
5. Viscosity
6. Kerosene retention
7. Penetration index
8. Oil absorption

MISCELLANEOUS TESTS

1. Tensile strength
2. Asbestos-cement strength
3. Color
4. Quantitative chemical analysis
5. Moisture content
6. Magnetic rating
7. Freeness or filtration

4. RESULTS AND DISCUSSIONS

The results obtained from the data collected are grouped under the following process headings:

- Crushing
- Drying
- Milling
- Aspiration

4.1 Crushing Circuit

4.11 Electrical Measurements

A summary of the measurements taken from the equipment in this circuit are shown in Table 7.

Electrical demand (kW) was calculated from the measured current (A), voltage (V), and power factor (PF) and applying the values to the formula

$$(\text{kW}) = \frac{\sqrt{3}\ \text{VA(PF)}}{1000}$$

To measure maximum and minimum amperage, readings were recorded from the local ammeters over a period of several minutes.

Table 7 indicates that both the jaw and the 7' shorthead cone crushers run at full loaded capacity periodically. On the average, they operate at 74% of the total power capacity. Their consumption can, however, fluctuate from 62% to 80% of the circuit's total energy capacity.

The dust collection units use about 25% of the total installed power.

TABLE 7 - Crushing Circuit

POWER MEASUREMENT CALCULATIONS		MOTOR H.P.	kW
No.	EQUIPMENT		AVG.
1.1	Apron Feeder	25/16.7	11.1/7.5
1.2	Jaw Crusher	250	153
1.3	Ty-Rock Screen - F800	25	4.9
1.31	Ty-Rock Screen - F800	25	5.0
1.4	7' Shorthead Cone Crusher	250	136
1.5	Jaw Crusher Dust Collector	75	23
1.6	Cone Crusher Dust Collector	75	18
1.7	Screen House Dust Collector	60	43

4.12 Flowrate

The average flow through the primary crushing circuit was 750 tonnes/hour, determined from weightometer information.

4.13 Size Distribution

The quarry feed varies in size distribution from 1m x 1m x 0.3m to fines. The large pieces are relatively soft and fracture easily.

4.14 Specific Power Consumption

From the power measurement calculations and a flowrate of 750 tonnes/hour, the specific power consumption was calculated. The results are shown in Table 8.

TABLE 8 - Crushing - Specific Power Consumption

	kWh/tonne	%
Comminution	0.39	74
Auxiliaries	0.13	26
Total	0.52	100

From the table, the power demand for comminution is minimal.

4.2 Drying Circuit

4.21 Electrical Measurements

The summary of the electrical measurements for the equipment in the circuit are listed in Table 9.

The equipment normally operates under constant load, except for the pulvomatic impactor (3.6). Even here, the fluctuation is minimal.

TABLE 9 - Drying Circuit

POWER MEASUREMENT CALCULATIONS		MOTOR H.P.	kW
No.	EQUIPMENT		AVG.
3.1	Ty-Rock Screen - F600	25	8.6
3.11	Ty-Rock Screen - F600	2 x 7.5	2 x 2.6
3.2	Pulvomatic Impactor	200	89
3.21	Pulvomatic Impactor	200	90
3.3	Ty-Rock Screen - F600	15	4.3
3.31	Ty-Rock Screen - F600	15	4.4
3.4	Concentration	-	15.4
3.5	5½' Shorthead Cone Crusher	200	68
3.6	Pulvomatic Impactor	200	103
3.7	Screen	10	3.4
3.71	Screen	15	12.8
3.8	Push-Pull Separator Fan	25	15.6
3.81	Push-Pull Separator Fan	10	5.2
3.9	Tower Dryer Draft Fan	100	72
3.102	Rotary Dryer Drive #3	60	47
3.103	Rotary Dryer Drive #4	60	33
3.112	Rotary Dryer Draft Fan #3	100	49
3.113	Rotary Dryer Draft Fan #4	100	53
3.114	Auxiliary Draft Fan	75	44
3.115	Auxiliary Draft Fan	75	39

4.22 Flowrate

Ore is reclaimed from wet rock storage at 625 tonnes/hour.

Normally, about 20% of the flow is fines (-28mm), which pass directly to the dryers.

The oversize fraction, which represents 50% of the screen feed, is crushed (3.2, 3.21). The middle cut is screened on an intermediate screen, the oversize fraction of which is combined with the crushed product. The combined fractions make up the feed to the secondary screening stage (3.3, 3.31).

The concentration circuit rejects up to 45% of the total feed to tailings, resulting in a "beneficiated" dry ore feed rate of 344 tonnes/hour. This is the rate used to determine the specific cumulative power consumption.

4.23 Size Distribution

Three crushing operations are involved in this circuit: the Pulvomatic impactors (3.2, 3.21), the cone crusher (3.5) and the Pulvomatic impactor for the concentration rejects (3.6).

Samples of the feed and discharge of the cone crusher were taken and a sieve analysis was run at the CCL Testing Laboratory in Belleville, Ontario.

The plant provided size distribution information for the two impactors.

Table 10 consolidates information from all three crushers.

TABLE 10 - Drying Circuit Size Distributions (% Passing)

LAC D'AMIANTE DU QUEBEC, LTEE						
	PULVOMATIC IMPACTOR (3.2)		CONE CRUSHER (3.5)		PULVOMATIC IMPACTOR (3.6)	
mm	FEED	DISCH.	FEED	DISCH.	FEED	DISCH.
133	100				100	100
75		100	100		95.5	99.2
50	47.9	85.0	88.0	100	76.8	88.0
38.1			79.0	94.4		
25.0	9.2	48.9	49.7	68.1	31.3	56.4
19.0	5.2	36.7	26.0	36.7	12.2	40.4
12.5	2.9	24.7	5.7	12.7	1.9	22.3
9.5			5.3	10.2		
6.3		14.0			0.7	10.4
4.75			2.6	6.8		
2.36			2.2	4.8		
1.60						3.9

4.24 Grindability Testing

Due to the fibrous nature of the mineral, grindability testing by the Hardgrove and Bond Index methods proved impossible.

4.25 Specific Energy Consumption

The electrical measurements reported in Table 9 and the beneficiated flowrate (4.22) were required to calculate the energy consumed in the circuit. The results are shown in Table 11.

TABLE 11 - Drying Circuit - Specific Power Consumption

Flowrate: 344 t/h beneficiated dry ore

	kWh/tonne	%
Comminution	1.02	46
Auxiliaries	1.20	54
Total	2.22	100

The comminution equipment includes the Pulvomatic impactors (3.2, 3.21, 3.6) and the 5½' Shorthead cone crusher (3.5).

Worthy of note, is the the air flow equipment's power requirement which is greater than that for comminution.

Comparative power consumption data is given in Table 12.

TABLE 12 - Drying Circuit
Comparative Power Consumption Analysis

	kWh/tonne	%
Comminution	1.02	46
Air Flow	1.04	47
Concentration	.04	2
Screens	.12	5
Total	2.22	100

4.26 Cumulative Power Consumption

A cumulative summary of the power requirements for obtaining dry beneficiated ore are shown in Table 13. The results indicate a fairly even split between comminution and auxiliary power use to this point.

TABLE 13 - Dry Ore Preparation
Cumulative Power Consumption

Flowrate: 344 t/h Beneficiated Dry Ore

	kWh/tonne	%
Comminution	1.72	54
Auxiliaries	1.45	46
Total	3.17	100

4.3 Milling Circuit

4.31 Electrical Measurements

The summary of the electrical measurements for the equipment in the circuit is listed in Table 14.

4.32 Flowrate and Size Distribution

The nominal flowrate is 375 t/h; but during our observation period it was actually 323 t/h for the circuit, or 107.7 t/h for each production line.

No individual sampling was done. However, from information supplied by the plant, size distributions are shown in Table 15.

TABLE 14 - Mill Rock Circuit Measurement

POWER MEASUREMENT CALCULATIONS		MOTOR H.P.	kW
No.	EQUIPMENT		AVG.
4.1	Screen	7.5	1.5
4.11	Screen	10	4.3
4.12	Screen	10	4.7
4.2	Torrey Impactor	75	36
4.21	Torrey Impactor	75	36
4.3	Screen	7.5	4.5
4.31	Screen	7.5	7.0
4.4	Torrey Impactor	75	31
4.41	Torrey Impactor	75	28
4.5	Screen	7.5	4.9
4.51	Screen	7.5	3.9
4.6	Denovan Impactor	150	53
4.7	Screen	5	3.6
4.71	Screen	5	3.5
4.8	J-M Fiberizer	125	41
4.9	Screen	5	4.1
4.91	Screen	5	3.8
4.100	Concentration	-	2.4
4.101	Concentration	-	2.6
4.11	J-M Fiberizer	150	64
4.12	Screen	5	3.7
4.13	Denovan Impactor	75	38

TABLE 15 - Mill Rock Circuit
Size Distributions (% Passing)

mm	TORREY (4.2)		TORREY (4.4)		DENOVAN (4.6)		JM FIBERIZER (4.8)	
	Feed	Disch	Feed	Disch	Feed	Disch	Feed	Disch
5.0	100	100	100					
38.1	99.0	99.8	99.7	100				
25.0	95.0	99.3	98.4	99.8				
19.0	88.0	96.5	95.0	99.3				
16.0	80.5	94.8	90.9	98.4				
12.5	65.4	89.6	81.8	95.1	100			
9.5	44.7	79.9	65.7	87.4		100		
6.3	23.8	64.9	47.1	74.9	53.9	73.9	100	100
2.36	6.0	39.5	18.4	43.9	28.8	40.6	57.3	84.7
1.40	3.3	25.0	6.2	24.6	11.4	18.9	13.2	57.6
1.00	2.7	17.9	3.8	17.1			7.4	39.8
0.600	2.4	13.5	2.2	12.4	4.6	7.3	3.7	28.7
0.425	1.4	9.9	1.6	9.1			3.0	21.0

4.33 Specific Power Consumption

The results from Table 14 and the flowrate for a single line of the circuit were the parameters used in determining specific power consumption.

TABLE 16 - Milling Circuit
Specific Power Consumption

Flowrate: 107.7 t/h Dry Ore (one line only)

	kWh/tonne	%
Comminution	3.04	86
Auxiliaries	0.50	14
Total	3.54	100

4.4 Fibre Grading

In this circuit, the aspiration vacuum fans are involved. The power consumed by the cleaning, grading and fiberizing equipment was not measured, as it is not directly related to comminution.

4.41 Electrical Measurements

TABLE 17 - Aspiration and Grading Circuit

POWER MEASUREMENT CALCULATIONS		MOTOR H.P.	kW
No.	EQUIPMENT		AVG.
5.1	Vacuum Fan Drive #1	350	217
5.11	Vacuum Fan Drive #2	350	223
5.12	Vacuum Fan Drive #3	350	239
5.13	Vacuum Fan Drive #4	350	226
5.14	Vacuum Fan Drive #5	350	219
5.15	Vacuum Fan Drive #6	350	226
5.16	Vacuum Fan Drive #7	350	209
5.17	Vacuum Fan Drive #8	350	247

4.42 Specific Power Consumption

The power consumption is high compared to other circuits in the mill.

The specific power consumption was calculated for the complete milling circuit based on a fibre production rate of 17.85 tonnes per hour. The results are shown in Table 18.

TABLE 18 - Aspiration
Specific Power Consumption

Flowrate: 17.85 t/h of Fibre (Total Mill)

	kWh/tonne
VACUUM CHAMBER	101.2

TABLE 19 - Fibre Production
Average Cumulative Power Consumption

(Based on 5.53% fiber content in the dry ore)

MILL CIRCUIT	TOTAL CONSUMPTION	AUXILIARIES		COMMINUTION	
	kWh/ tonne	kWh/ tonne	% Total Consumption	kWh/ tonne	% Total Consumption
Crushing	17.2	4.5	2	12.7	6
Drying	40.1	21.7	10	18.4	8
Milling	64.1	9.1	4	55.0	25
Aspiration	101.2	101.2	45	-	-
TOTAL	222.6	136.5	61	86.1	39

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

From the study, it can be concluded that:

- the results are considered as a fair representation of the power consumption for comminution by the industry;
- the air handling system is a significant energy consumer;
- the fibre to dry rock ratio of 5.53 percent requires the mining of large quantities of ore to achieve required production rates;
- many comminution stages are required to continuously release the fibre from the host rock.

5.2 Recommendations

Due to the stringent dust control requirements and the present high energy consumption of the air handling system, the use of wet grinding should be investigated.

APPENDIX

INDUSTRY REVIEW

GENERAL INFORMATION

The Mineral and its Processing

Asbestos is the generic term used for a number of fibrous mineral silicates found in nature. The six naturally occuring varieties are: chrysotile, amosite, crocidolite, anthophyllite, tremolite and actinolite. The most important variety, chrysotile, which accounts for 93% of the world production, is the only one mined in Canada. It is a fibrous form of serpentine which can be either white, gray, green or yellowish. Crocidolite and amosite are used in industrial applications in other countries.

The theoretical chemical formulae for the three important types of asbestos are as follows:

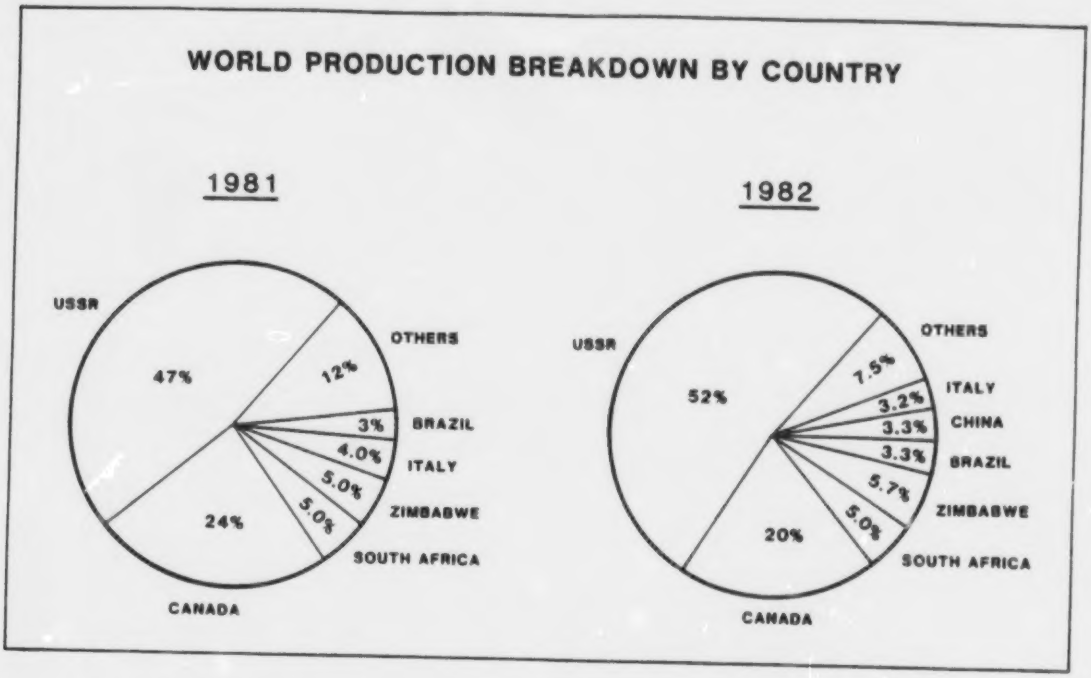
Chrysotile: $3MgO, 2SiO_2, 2H_2O$

Crocidolite (blue asbestos): $Na_2O, Fe_2O, 3FeO, 8SiO_2, H_2O$

Amosite: $5.5FeO, 1.5MgO, 8SiO_2, H_2O$

The world production was estimated at about 4,200,000 tonnes in 1982. U.S.S.R. is the world's largest producer, followed by Canada. The breakdown of world production by country for 1981 and 1982 is illustrated in Figure I.

FIGURE I - Breakdown of the World Production by Country (1981 - 1982)[2]



Source: Canadian Mining Journal, February 1983 & 1984.

The ore is milled to recover fibres. The grading of the final product depends mainly on fibre length distribution and degree of openness.

Primary crushing may be done in underground stations or in surface plants by jaw or gyratory crushers. The reduction is normally about 18 cm at this point. It is commonly followed by secondary crushing using either gyratory or cone crushers.

An early concentration stage occurs in these circuits to reject barren rock by selective impact crushing and screening, and by magnetic separation. The ore is dried in rotary or vertical towers to remove the surface moisture without dehydration.

The release and separation of fibre from the host rock is achieved through successive stages of comminution by impact. The released fibre is removed by screening and aspiration. The type of machines used in these stages depends on the required degree of openness.

Each product obtained from primary fibre separation is treated in a separate cleaning circuit and kept separate until final grading. Various grades are derived by using vibrating screens or rotary type graders. The fibre is then sized, cleaned and blended to meet the customers' requirements.

A complex air handling and dust collection system is necessary for collecting and conveying material.

The Canadian Industry

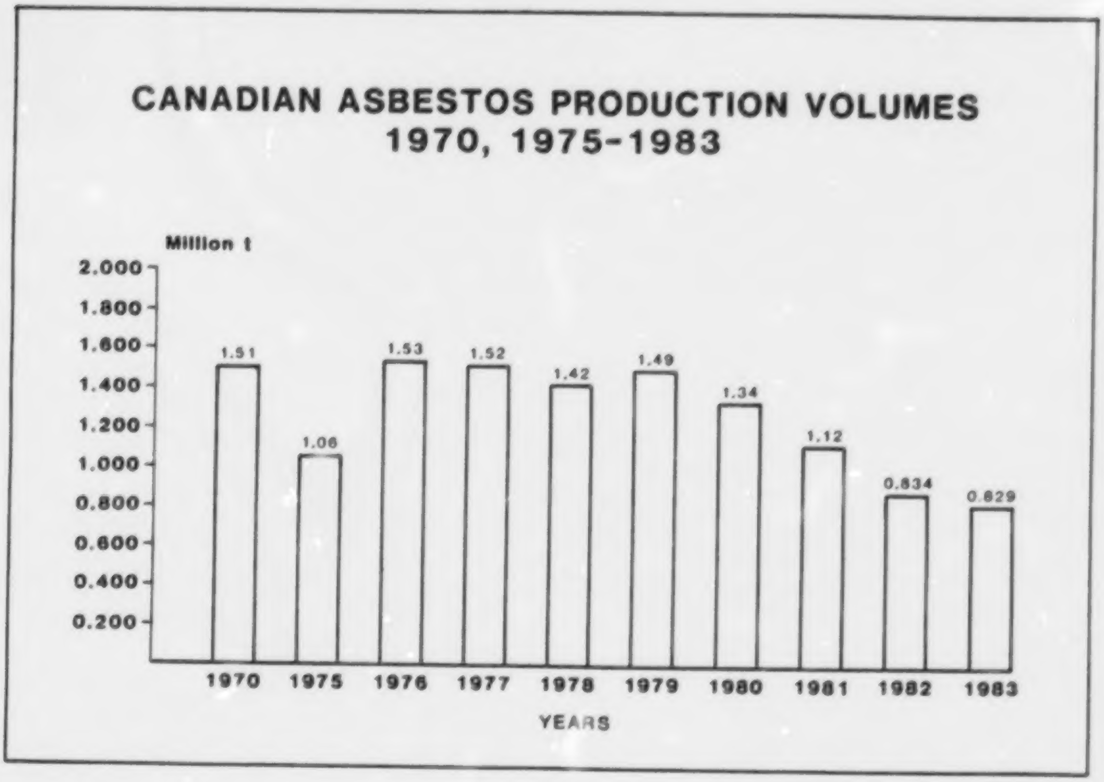
In 1870, asbestos was first mined in Canada in the province of Quebec. Today, Quebec remains the principal producer, representing about 85 to 90 percent of Canada's production. Other operations are in British Columbia and Newfoundland. A breakdown by province for 1982 and 1983 is shown in Table 1.

TABLE 1 - Breakdown of the Asbestos Production by Province (1982-1983)[2]

Province	1982		1983	
	Tonnes	Million $	Tonnes	Million $
Quebec	745 000	298	717 000	315
British Columbia	76 000	57	80 000	70
Newfoundland	13 000	9	32 000	17
Total	834 000	364	829 000	402

Canadian production volumes in 1970 and from 1975 to 1983, can be seen in Figure II.

FIGURE II - Canada, Production Volumes 1970, 1975-83[2]



Source: Canadian Mining Journal, February 1983 & 1984.

Exports generally account for 95% of Canadian production and represent 50% of the world's asbestos exports.

Table 2 lists Canadian producers, mine locations and mill capacities.

TABLE 2 - Canadian Asbestos Producers, 1983[2]

PRODUCERS	MINE LOCATION	MILL CAPACITY (tonnes)		REMARKS
		ore /day	fibre /year	
Baie Verte Mines Inc.	Baie Verte, Nfld.	6 600	80 000	Open pit
Carey Canada Inc.	E. Broughton, Que.	6 800	210 000	Open pit. Mainly produces groups 6 & 7.
Asbestos Corporation Limited				Purchased in 1982 by Société nationale de l'amiante (SNA) (Que. Crown corp.)
Asbestos Hill mine	Putunig, Que.	5 400	90 000	Mining ceased indefinitely. Final processing of fibre in W. Germany.
British Canadian mine	Black Lake, Que.	12 000		Open pit, two milling plants
King-Beaver mine	Thetford Mines, Que.	7 000	210 000	Underground & open pit.
Normandie mine	Black Lake, Que.			Reserves exhausted. Mill processes K-B open pit ore.
Bell Asbestos Mines, Ltd.	Thetford Mines, Que.	2 700	55 000	Underground. Purchased in 1980 by SNA (Quebec Crown corp.)
Lake Asbestos of Quebec, Ltd	Black Lake, Que.	9 000	235 000	Open pit.
National Mines Division	Thetford Mines, Que.	4 000		Open pit.
JM Asbestos Inc. Jeffrey mine	Asbestos, Que.	30 000	645 000	Open pit (western world's largest known asb. deposit).
Brinco Mining Limited Cassiar mine	Cassiar, B.C.	5 000	100 000	Open pit.

Chrysotile is the result of the alteration and metamorphosis of basic igneous rocks rich in magnesium silicate. The approximate composition of chrysotile is shown in Table 3.

TABLE 3 - Approximate Composition of Chrysotile[4]

Component	%
SiO_2	37-44
MgO	39-44
FeO	0-6
Fe_2O_3	0.1-5
Al_2O_3	0.2-1.5
H_2O	12-15

Typical impurities in chrysotile are iron, chrome and nickel.

Some physical qualities of interest include large surface area, good resistance to heat and oxydation, and high flexibility. Chrysolite also mixes well with resins and cements and has good spinnability.

Representative physical properties are shown in Table 4.

TABLE 4 - Properties of Chrysotile Fibre[4]

Specific Heat, kJ/kg.K	1.113
Tensile Strength, MPa	551.6 - 689.5
Fusion Point, °C	1521

Asbestos fibre is classified and sold by groups. The longest fibres are the most expensive. Groups 7, 8 and 9 are graded by bulk density measure.

The major uses of asbestos are listed in Table 5.

TABLE 5 - Possible Uses of Chrysotile Asbestos Fibre

Fibre Class	Groups	Uses
LONG	1 and 2 Crudes	Processed industrially into long spinning fibres used in textiles and the electrical industry.
	3 Milled	Textiles, asbestos papers, packings, brake linings, clutch facings, pipe coverings, and insulating blocks.
MEDIUM	4 Milled	Reinforcing in asbestos-cement products: pipe, shingles, jackets pipe coverings, asbestos-cement packing, gaskets, millboards, roof coatings and plastics.
	5 Milled	Asbestos-cement sheets, corrugated or flat boards, pipes, electrical panels, asbestos papers, millboards, pipe coverings, brake linings, asbestos-cements, roof coatings, putties and plastics.
	6 Milled	Asbestos-cement shingles, corrugated or flat sheets, boards, brake linings, asbestos papers, millboards, asphalt roof coatings, putties and plastics.
SHORT	7, 8, 9 Milled	Certain papers, insulating cement, asphalt roof coatings, putties, paints, welding rods, floor tiles, plastics, acoustical plaster, fibrated greases, oil well muds.

Uniformity of product is one of the most important characteristics demanded by the consumer. Fibre quality is controlled during production by tests made on samples obtained by automatic samplers in the milling circuit.[3]

The only test recognized in Canada is the Quebec Asbestos Mining Association (QAMA) classification known as the Quebec Standard Test (QST). It serves as a production control and as the basis for sale of Canadian asbestos.

The QST is a dry screen analysis which gives the fibre length distribution. This test is made in a QST machine consisting of a nest of three sieves with 12.5 mm, 4.75 mm and 1.70 mm openings and a pan. A test is made with a 1 lb fibre sample which is mechanically shaken for 600 revolutions at 328 rpm. The results, in terms of the weight of fibre remaining on each screen and pan, indicate the relative lengths of the fibres, as shown in Table 6.[3,4]

Other tests are made at the request of consumers to meet their specific needs: viscosity, absorption, fines content, grit, bulk density, soluble salts, magnetic content, compressibility, flexibility, flexing, tensile strength, colour, surface area, filterability, strength units and air permeability.[4]

TABLE 6 - Typical QST Results for the Major Fibre Groups

Fibre Class	Group	½ in. oz	4 mesh oz	10 mesh oz	Pan oz	Total oz
Long Spinning Fibre	3	4	7	4	1	16
Medium Asbestos-Cement Fibre	4	0	4	8	4	16
Paper Stock Fibre	5	0	0	12	4	16
Paper and Shingle Fibre	6	0	0	7	9	16
Shorts	7	0	0	0	16	16

Examples of tests required for some specific uses are shown in Table 7.

TABLE 7 - Asbestos Tests for Specific Uses

PRODUCTS	TESTS REQUIRED
Asbestos-Cement Grades	Strength, fibre length and distribution, filtering rate, dust content
Paper Grades	Length distribution, colour, degree of openness
Plastic Industry	Dust content, grit content, iron and magnetite content

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REFERENCES

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THE CEMENT INDUSTRY

ENERGY CONSERVATION IN THE INDUSTRIAL MINERALS PROCESSING SECTOR - COMMINUTION

(Phase I - Plant Studies)

Work on this Project was conducted by
Canada Cement Lafarge Ltd.,
under the auspices of the
Canada Centre for Mineral and Energy
Technology; Energy, Mines and Resources, Canada

DSS File Number: 23SQ.23440-2-9016A
DSS Contract Serial Number: OSQ82-00228

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APPENDIX - Industry Review

1. General Information
2. Product Characteristics
3. Quality Criteria

REFERENCES

1. INTRODUCTION

Cooperating Company:

Canada Cement Lafarge Ltd.

Plant Location:

St. Constant, Quebec

The study follows the format of the others in the series. It introduces first the company that cooperated in the study. A description follows of the comminution processes monitored during the field work at the visited plant. The measurements made and results obtained are then reported and discussed and conclusions are drawn.

For readers who are not familiar with the cement industry, an appendix entitled "Industry Review" is added. Details concerning data collection and field work, as well as other raw data or measurements, are available in working papers.

2. COMPANY DESCRIPTION

2.1 History and Organization

The history of Canada Cement Lafarge dates back to 1909 and the formation of the Canada Cement Company. It was created by the amalgamation of a number of companies with plants in Quebec at Montreal and Hull, and in Ontario at Belleville and Port Colborne. Shortly afterwards, the company acquired cement manufacturing facilities at Exshaw, Alberta.

The amalgamation was the result of over-expansion of cement capacity in the previous decade, leading to stiff competition among producers with little or no profits or cash flow for operation or improvement of factilities. The newly-formed company acted as a stabilizing force in the Canadian cement industry, providing more even pricing and eliminating much of the over-capacity. The operation was well organized and generated profits so that finances became available for a continuous program of improvement. The head offices of the Canada Cement company were established in Montreal and were moved to the Canada Cement Company Building in downtown Montreal in 1922.

The first completely new facility constructed by the company was a fully integrated manufacturing plant at Fort Whyte near Winnipeg, Manitoba.

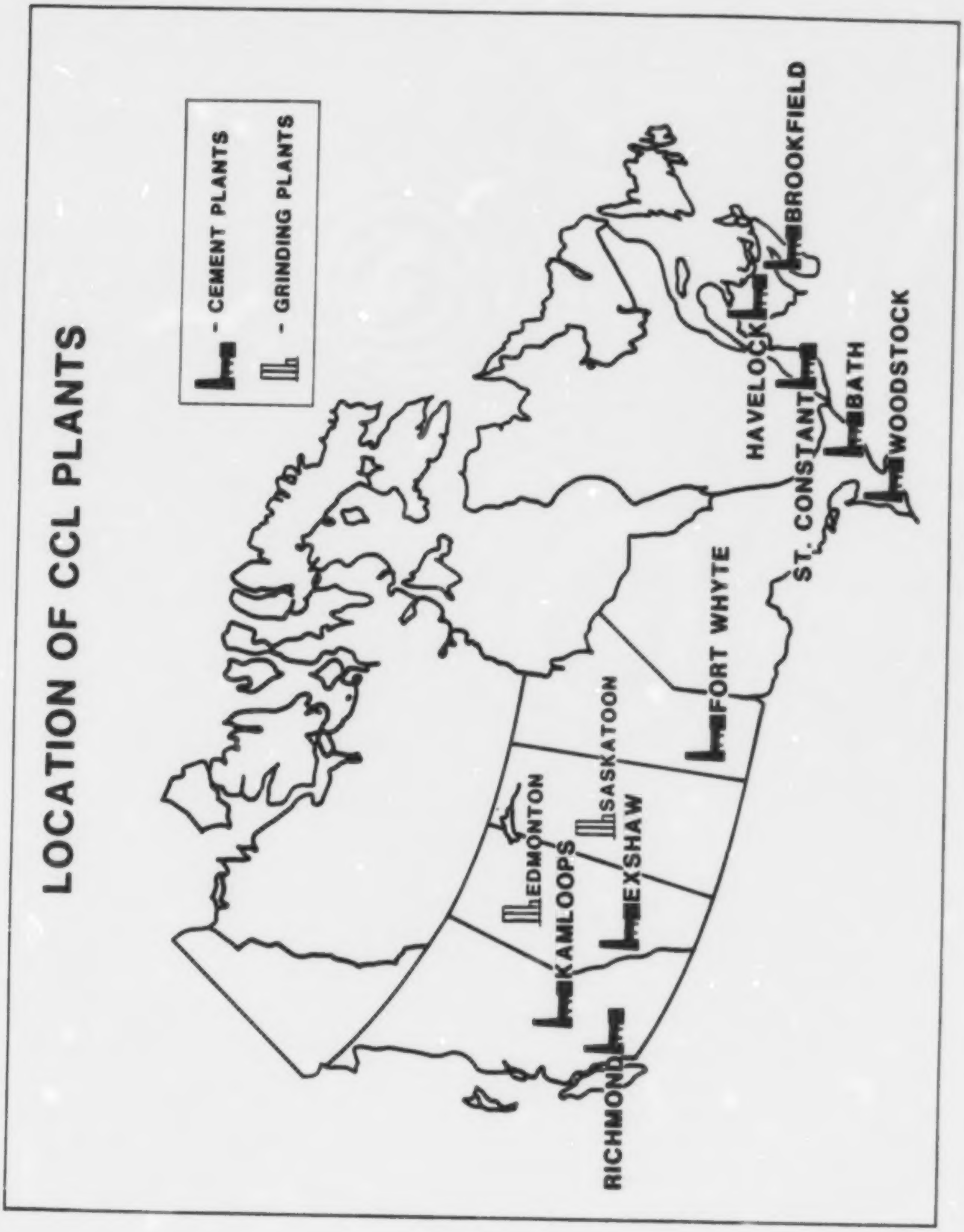
One of the major programs carried out by the company was the conversion of its kilns from the dry to the wet process. This was begun in the late twenties and continued into the thirties. The wet process was preferable because wet raw grinding was cleaner and the raw kiln feed, in the form of a slurry, was easier to handle and blend. Also, in those days, a single large wet kiln could replace several small dry kilns.

The demand for cement fell sharply during the depression and did not recover to pre-depression levels until after the Second World War. When the war ended, many long-deferred construction projects were begun and the cement industry in Canada witnessed several boom years. The Canada Cement Company accelerated its investment program, and began construction of new facilities. A dry-process plant at Havelock, New Brunswick was brought on-stream in 1951 and was the first cement manufacturing facility in the Maritimes. Interest was reviving in the dry-process because of the increased fuel efficiency. Another new plant was started-up in 1956 at Woodstock, Ontario, and in 1965, a second Maritime plant went into operation at Brookfield, Nova Scotia.

Along with its efforts directed towards its cement manufacturing facilities, the company, during the sixties, established the practice of vertical integration, becoming involved in supplying ready-mixed concrete, preformed concrete products and aggregates.

In 1970, the company merged with Lafarge Canada Ltd., forming Canada Cement Lafarge Ltd. Lafarge Canada had been active in Canada since the fifties and had established plants at Richmond and Kamloops, British Columbia, and at St. Constant, Quebec. These operations, combined with those of the Canada Cement Company, gave the new company, Canada Cement Lafarge Ltd., manufacturing and distribution facilities in all regions of the country. (See map on page 4).

Since the merger, Canada Cement Lafarge has continued its program of expansion and modernization of its facilities including construction of a new plant at Bath, Ontario, and two new kilns at Exshaw.



LOCATION OF CCL PLANTS

2.2 Products

The company's products, as defined by the CSA, are shown in Table 1 below.

TABLE 1 - CSA Classification of Portland Cements

NAME	TYPE	APPLICATION
Normal	10	For use in concrete construction when the special properties of the other types are not required.
Moderate	20	For use in general concrete construction exposed to moderate sulphate action, or when moderate heat of hydration is required.
High Early	30	For use when high early strength is required.
Low Heat	40	For use when low heat of hydration is required.
Sulphate-Resistant	50	For use when high sulphate-resistance is required.
Oil Well	58-59	For cementing the casing in place in oil wells.
Masonry	60	For using in bonding brick or concrete block.

2.3 Raw Materials

Raw materials for the Portland cement manufacturing process are calcium carbonate, silica, alumina and iron, which are suitably proportioned to give the right balance of oxides after pyroprocessing.

The major constituent is calcium carbonate which is generally obtained from limestone. Other sources are chalks, marls and oyster shells.

Sources of silica are sand, sandstone, clay or shale while alumina is found in shale, clay, fly ash or bauxite. Iron is supplied by iron ore, mill scale or fly ash.

Since cement making is a chemical process, there is considerable flexibility in the choice of raw materials. The available limestone may contain some or all of the other required components in varying degrees. So-called "natural cement" rocks have the required composition for cement making.

3. PROCESS DESCRIPTION

3.1 General

The process at St. Constant, despite having the capacity of producing about 900,000 tonnes of finished product per year, is relatively straightforward from a process flow point of view (Figure I).

The process is broken down into four major functions: quarrying and crushing, raw grinding, burning and finish grinding. At St. Constant the stone is blasted and trucked to the crusher. The crushed stone goes through a stacker-reclaim system which serves both to store and blend the stone. The stone is then mixed with other raw materials, sand and iron, which serve to adjust the chemical composition of the mix prior to grinding in the raw mill. The resulting raw mix is stored and blended in aeration silos and fed to the kilns for pyroprocessing. The resulting clinker is cooled and stored or fed directly to the finish mill where it is ground with a small amount of gypsum.

3.2 Quarrying and Crushing

Blasted rock from the quarry is dumped by quarry truck into a hopper, leading to a vibrating feeder-grizzly (Figure II). The rock is then fed directly to a 700 HP Hazemag rotary crusher and conveyed to two vibrating screens operating in parallel. The +19 mm stone is screened out and returned to the crusher. The product from the screens is transported a distance of 850 meters on a belt conveyor to the storage hall. Table 2 presents the equipment list for the crushing department.

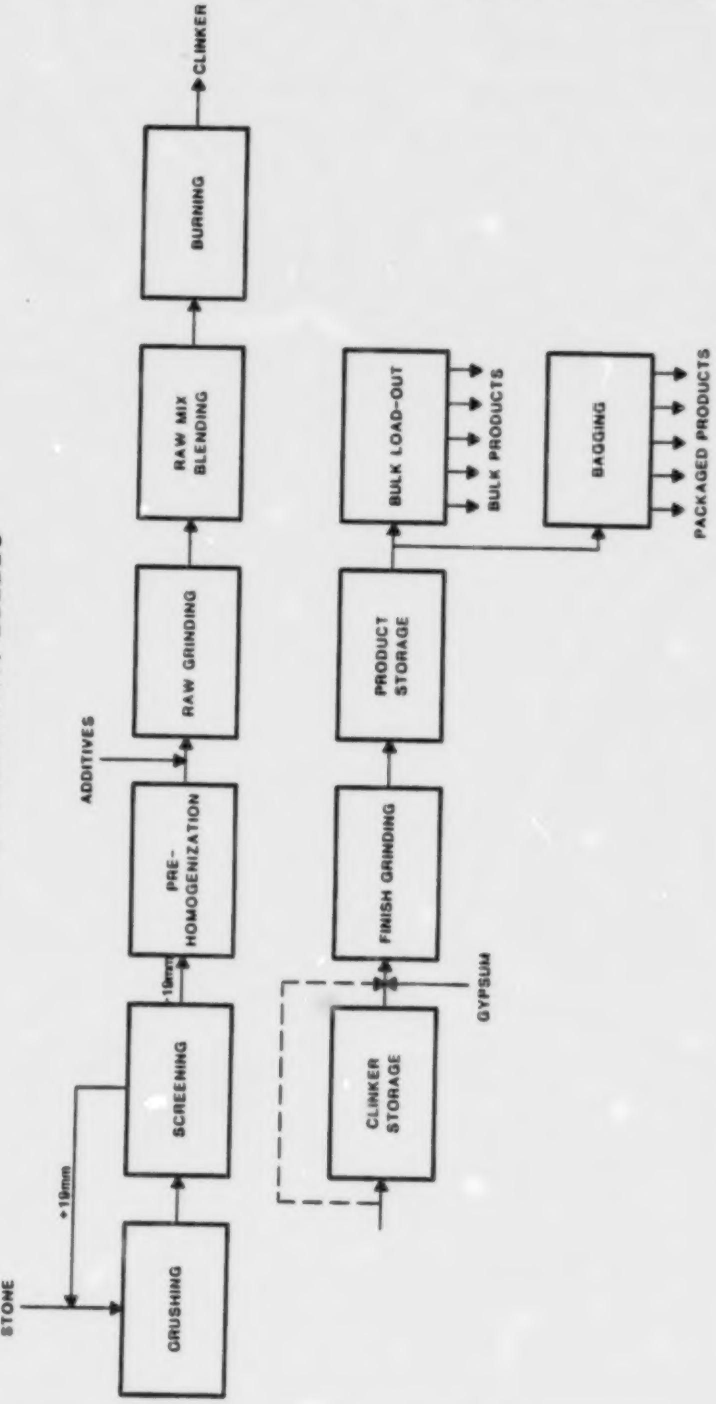


Figure I - PROCESS FLOW SHEET
CANADA CEMENT LAFARGE LTD
ST CONSTANT, QUEBEC

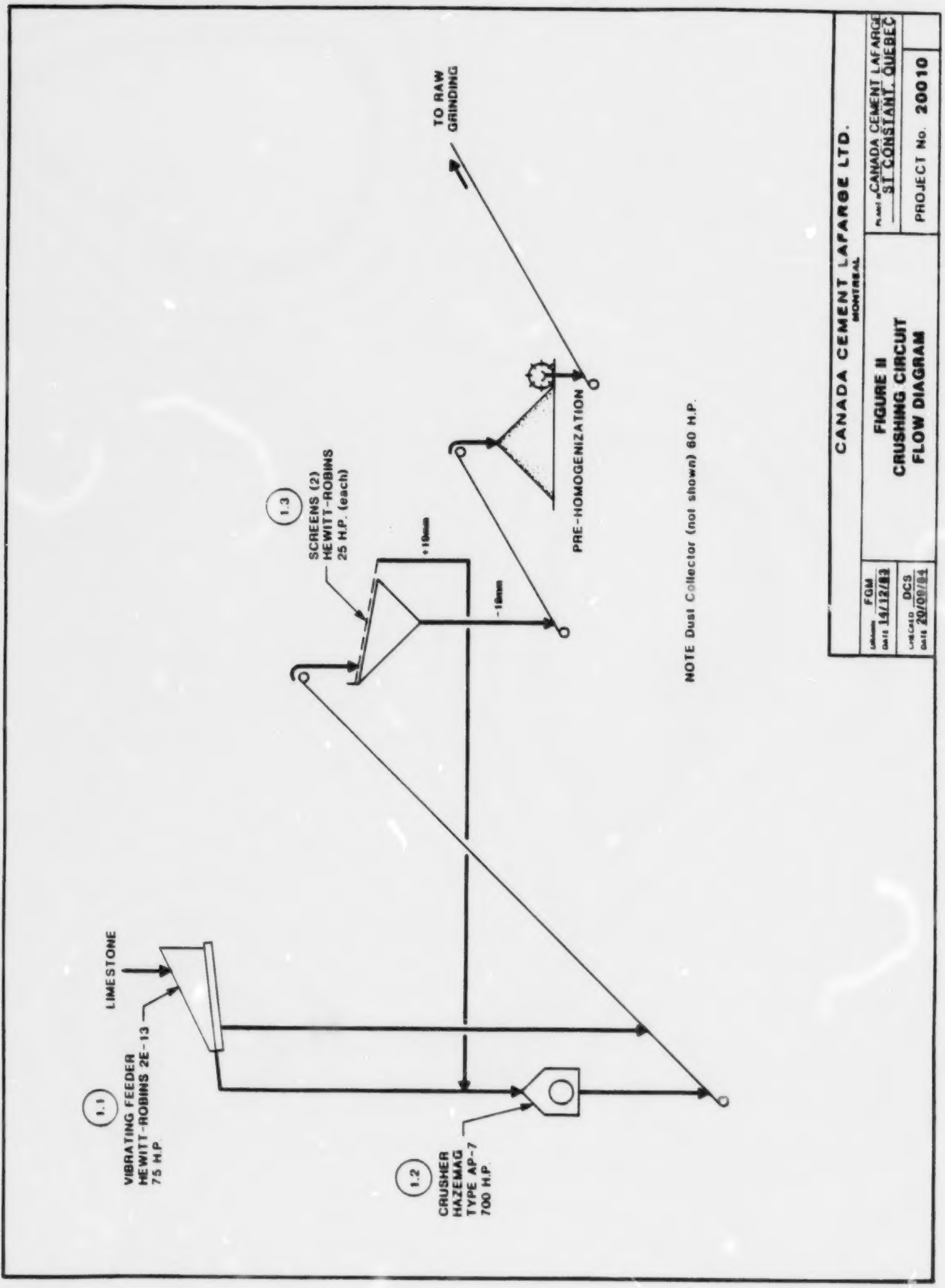

TO RAW GRINDING
1.3
SCREENS (2)
HEWITT-ROBINS
25 H.P. (each)
+10mm
-10mm
PRE-HOMOGENIZATION
NOTE Dust Collector (not shown) 60 H.P.
LIMESTONE
1.1
VIBRATING FEEDER
HEWITT-ROBINS 2E-13
75 H.P
1.2
CRUSHER
HAZEMAG
TYPE AP-7
700 H.P.
CANADA CEMENT LAFARGE LTD.
MONTREAL
FIGURE II
CRUSHING CIRCUIT
FLOW DIAGRAM
DRAWN FGM
DATE 14/12/83
CHECKED DCS
DATE 20/09/84
PLANT CANADA CEMENT LAFARGE
ST CONSTANT, QUEBEC
PROJECT No. 20010

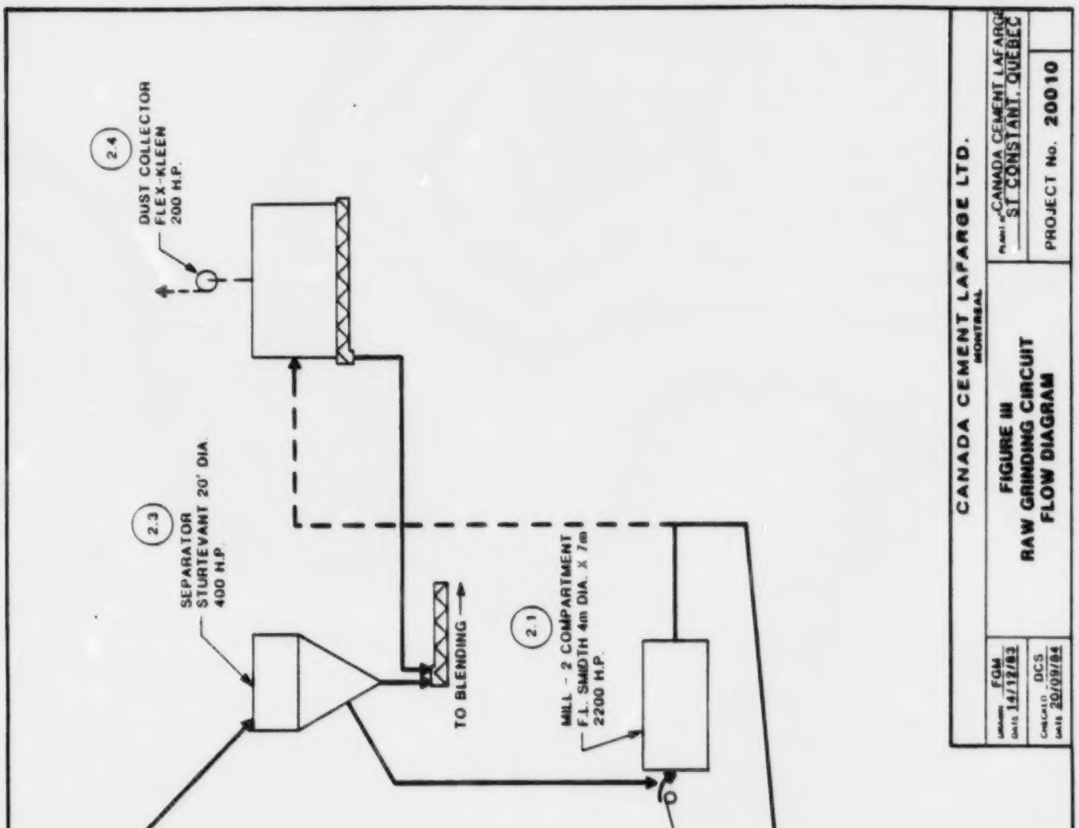
TABLE 2 - Crushing - Equipment List

EQUIPMENT		MOTOR		
No.	TYPE/MAKE/MODEL	HP	VOLTS	AMPS
1.1	Vibrating Feeder Hewitt-Robins 2E-13	75	550	75
1.2	Crusher Hazemag Type AP-7	700	4160	86
1.3	Screens (2) Hewitt-Robins	25	550	24
1.4	Dust Collector Norblo 6 Compartment	60	550	57

At the storage hall the stone is processed through a stacking-reclaiming system which serves to even out chemical variation in the stone as quarried. With this system, a pile is built by spreading the stone over the entire width of the pile giving layers of different stone. Once the pile is complete, the material is reclaimed with a bucket wheel and discharged to a belt conveyor. In contrast to the way the pile is built, it is reclaimed by taking cuts across the pile, traversing the layers. Thus, by mixing stone crushed at various times, the variation is reduced. In practice, 2 piles are used, one being reclaimed as a new one is built. This process is referred to as pre-homogenization.

3.3 Raw Grinding

The stone is reclaimed to a bin for feeding to the raw mill (Fig. III). It is necessary for the stone to be dried before further processing. Thus, instead of being fed directly to the mill, the stone is fed into the mill


2.4
DUST COLLECTOR
FLEX-KLEEN
200 H.P.
2.3
SEPARATOR
STURTEVANT 20' DIA.
400 H.P.
TO BLENDING
2.1
MILL - 2 COMPARTMENT
F.L. SMIDTH 4m DIA. X 7m
2200 H.P.
2.2
ELEVATOR
REXNORD
150 H.P.
STONE BIN
ADDITIVES
FROM PRE-HOMOGENIZATION
CANADA CEMENT LAFARGE LTD.
MONTREAL
FIGURE III
RAW GRINDING CIRCUIT
FLOW DIAGRAM
PLANT: CANADA CEMENT LAFARGE
ST CONSTANT, QUEBEC
PROJECT No. 20010
DRAWN FGM
DATE 14/12/83
CHECKED DCS
DATE 20/09/84

discharge elevator where it mixes with material from the mill and then to the air separator. The stone is dried in the separator by contact with hot gases supplied by an external heater and then is fed along with the separator rejects to the mill as fresh feed.

Supplementary raw materials, sand and iron, which constitute a small fraction of the total mill feed, do not need to be dried separately and are fed directly to the mill.

Raw mill #2 at St. Constant is a two compartment ball mill driven by a 2200 HP motor through reduction gears. Mill feed material passes through the mill by fluid action, intermingling with the ball charge and undergoing comminution. The mill discharge material is conveyed by elevator to the separator where classification takes place by gravitational and centrifugal forces. Coarse particles fall or are thrown into a central "rejects" cone and are returned to the mill. The fine particles are swept to the outer cone.

Mill air sweep is accomplished by an exhaust fan. Dust laden air passes from the mill and is carried through a duct to a baghouse dust collector before being exhausted. Drying gases from the separator also pass through the baghouse. Collected dust is returned to the ground product.

The equipment list for raw grinding is presented in Table 3.

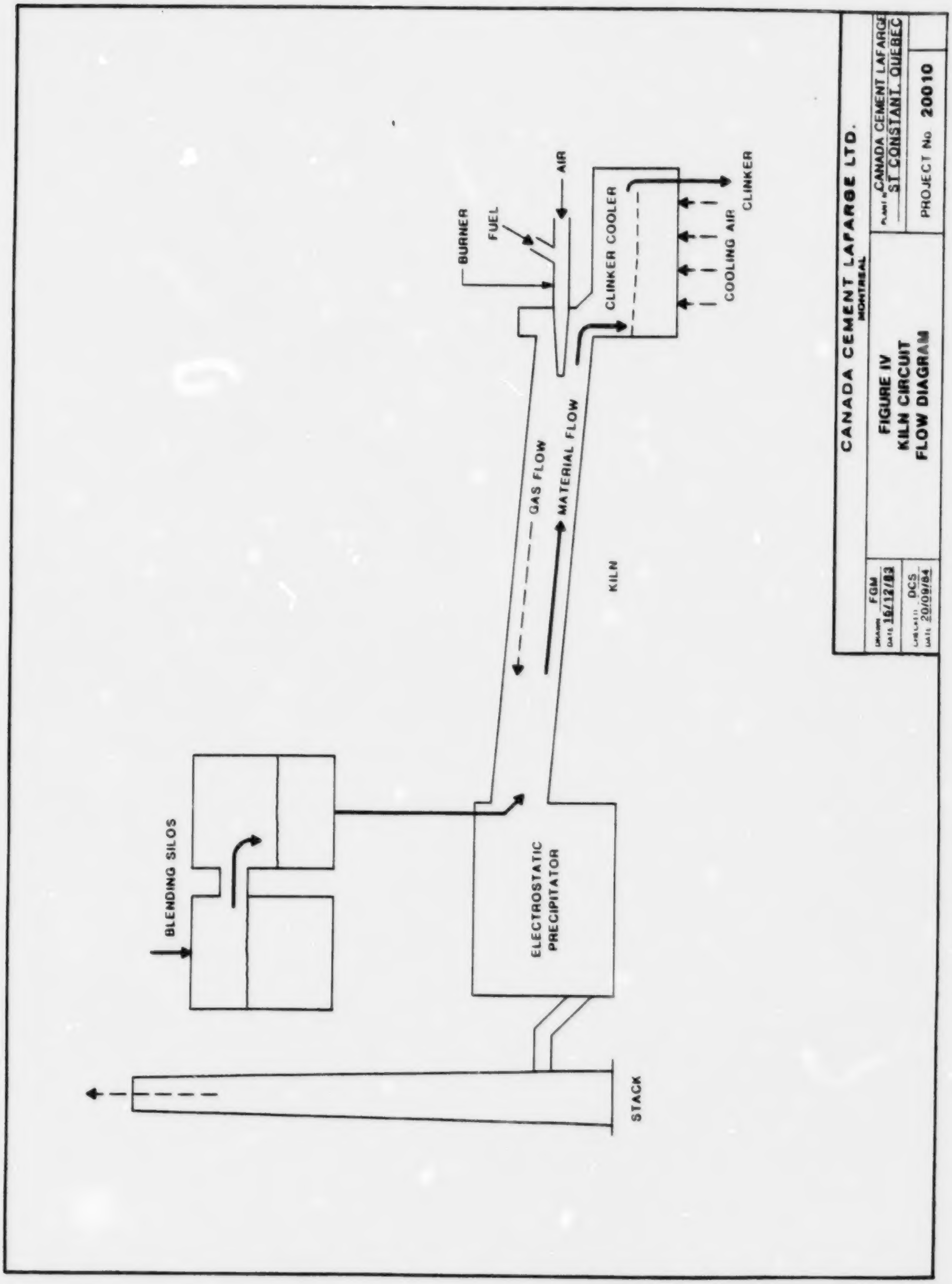
TABLE 3 - Raw Grinding - Equipment List

EQUIPMENT		MOTOR		
No.	TYPE/MAKE/MODEL	HP	VOLTS	AMPS
2.1	Mill - 2 Compartment F.L. Smidth 4 m dia. x 7 m	2200	4000	310
2.2	Elevator - Rexnord	150	575	134
2.3	Separator Sturtevant 20' dia.	400	4160	54
2.4	Dust Collector - Flex-Kleen	200	575	176

Regular sampling and testing ensure the raw mix meets the chemical and physical targets. Chemical composition is determined by x-ray. Raw mix fineness is checked by sieve.

3.4 Burning

The heart of the cement making process is the rotary kiln (Fig. IV). The kiln is a metal tube lined with refractory material and installed on a system of rollers so that it can be turned, usually at the rate of 1-1½ rpm. The two 4.6 x 122m kilns at St. Constant are termed long dry process since the kiln feed is in dry powder form and all steps of pyroprocessing take place in the kiln. Feed material is moved through the kiln by the rotary action and the fact that the kiln is sloped downwards toward the discharge end. The material passes counter-current to hot gases generated by fuel combustion at the discharge end, taking about 90 minutes to move from inlet to outlet.


BLENDING SILOS
ELECTROSTATIC PRECIPITATOR
STACK
KILN
GAS FLOW
MATERIAL FLOW
BURNER
FUEL
AIR
CLINKER COOLER
COOLING AIR
CLINKER
CANADA CEMENT LAFARGE LTD.
MONTREAL
FIGURE IV
KILN CIRCUIT
FLOW DIAGRAM
DRAWN FGM
DATE 16/12/83
CHECKED DCS
DATE 20/09/84
PLANT CANADA CEMENT LAFARG
ST CONSTANT, QUEBEC
PROJECT No 20010

As kiln temperature rises, residual moisture in the kiln feed is driven off prior to calcining, where the limestone decomposes to carbon-dioxide and lime. The temperature is further raised until part of the material becomes liquid and the mineral compounds are formed. This is termed clinkering. The temperature then drops slightly before the clinker is discharged from the kiln so that the material solidifies into nodules. The clinker drops from the kiln into the cooler where air is forced through the bed of clinker. Part of the cooling air is recovered and used for combustion in the kiln. The cooled clinker is transferred to storage or directly to finish grinding.

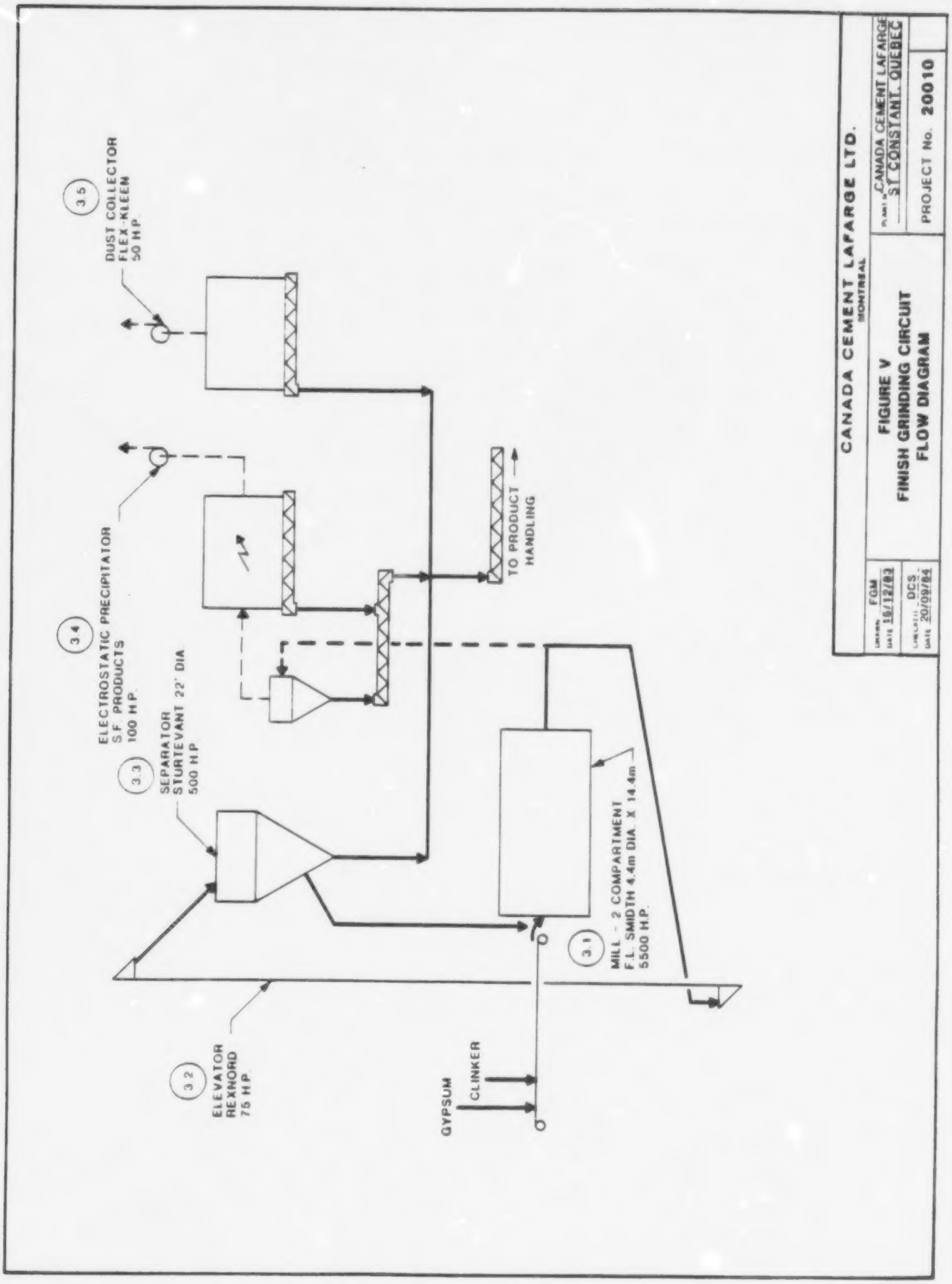
Dust-laden gases leaving the feed-end of the kiln are cleaned by electrostatic precipitation before being exhausted. Under proper operation of kiln and precipitator, virtually all dust is removed from the kiln gases.

The kilns at St. Constant can be fired with gas or Bunker "C" oil.

3.5 Finish Grinding

Finish mill #2 at St. Constant is a 2 compartment ball mill (Fig. V) driven by a 5500 HP motor through reduction gears. Clinker is fed directly to the mill by weighfeeder and a controlled amount of gypsum is added. The mill discharge goes via bucket elevator to an air separator which classifies the material into a product specification fine stream, and a reject stream which is returned to the mill.

The mill air sweep goes through the mill and is ducted to 2 cyclones arranged in parallel. The partially de-dusted



CANADA CEMENT LAFARGE LTD.
MONTREAL

FIGURE V
FINISH GRINDING CIRCUIT
FLOW DIAGRAM

air then passes through an electrostatic precipitator where it is cleaned before being exhausted.

The mill discharge temperature is regulated by water spray which also serves to adjust the relative humidity of the air before being passed to the precipitator. A baghouse dust collector de-dusts separator, elevator and air-slides. Dust from cyclones, electrostatic precipitator and baghouse is returned to the finished product. The equipment list for finish grinding is shown in Table 4.

TABLE 4 - Finish Grinding - Equipment List

EQUIPMENT		MOTOR		
No.	TYPE/MAKE/MODEL	HP	VOLTS	AMPS
3.1	Mill - 2 Compartment F.L. Smidth 4.4 m dia. x 14.4 m	5500	4000	778
3.2	Elevator - Rexnord	75	575	67
3.3	Separator - Sturtevant 22' dia.	500	4000	72
3.4	Electrostatic Precipitator S.F. Products	100	550	94
3.5	Dust Collector - Flex-Kleen	50	575	46

Regular sampling and testing is done on the cement as it is produced. Chemical composition is determined by x-ray with special attention to SO_3 content which is adjusted by gypsum addition. The Blaine fineness and percent passing 45 um is also checked regularly.

The finished product is conveyed to the storage silos and from these can be transferred to the bulk loading silos or packing machines for bagging.

4. RESULTS AND DISCUSSION

4.1 Crushing

4.11 Electrical Measurements

Power levels in kilowatts for the crushing department (Table 5) were calculated from measured amp, voltage and power factor. The results show the feeder is reasonably well loaded electrically and, at the maximum, is drawing nearly full-load power. The crusher, on average, is operating well within its power limit and, even at maximum, does not closely approach its capacity.

TABLE 5 - Crushing - Measurements

		MOTOR HP	POWER OBSERVATIONS - KW		
No.	EQUIPMENT		MAX.	MIN.	AVG.
1.1	Feeder	75	52	40	46
1.2	Crusher	700	450	369	404
1.3	Screens #1	25	13	13	13
	#2	25	12	12	12
1.4	Dust Collector	60	54	54	54

Both screens are operating at steady power levels and are well under electrical capacity. The dust collector fan, although operating steadily, was shown by the measurements to be operating above its power limit. However, this does not appear to be causing any problems for the over-all crushing operation.

4.12 Flowrates

The production rate of the crushing department varies depending on the moisture content of the quarry-run stone. Plant experience has shown that the production rate varies from 400 tph under damp, muddy conditions to 425 tph under dry conditions. At the time of the plant visit, conditions were wet and the production rate was taken as 400 tph.

4.13 Crusher Feed Size Distribution

Due to the size of crusher feed, no sample was taken. However, the material was observed during the visit and estimated to have the following characteristics:

Maximum size : 1.25 m
Average size : 20 cm
Minus 4 cm : 30%

Stone from the crushing circuit is the major feed constituent to the raw mill.

Much of the fine material in the crusher feed consists of overburden material which is quarried with the stone.

4.14 Specific Energy Consumption

The specific power consumption of the crushing department (Table 6) as determined by the measurements is modest. Because the large size of the feed, the ultimate fineness achieved in crushing (-19 mm) is not great.

TABLE 6 - Limestone Crushing Specific Power Consumption

Flowrate: 400t/h

	kWh/tonne	%
Comminution	1.01	76.5
Auxiliaries	0.31	23.5
Total	1.32	100.0

Although a major portion of the electrical consumption is due directly to comminution, a significant fraction of the consumption arises from auxiliaries. The main cause of this is the dust collector fan which was determined to be operating above its capacity.

4.2 Raw Grinding

4.21 Electrical Measurements

Observed power levels for the raw mill (Table 7) show that the mill motor is operating at a very steady level and practically at its limit. The elevator, while showing some variation, is operating well under capacity. The separator motor shows some variation but does not approach its limit. The dust collector fan varies somewhat in its power level but remains easily within its capacity.

TABLE 7 - Raw Grinding - Measurements

No.	EQUIPMENT	MOTOR HP	POWER OBSERVATIONS - KW MAX.	MIN.	AVG.
2.1	Mill	2200	1635	1634	1635
2.2	Elevator	150	59	52	55
2.3	Separator	400	122	117	119
2.4	Dust Collector	200	97	90	93

Variation in power level of the elevator is related to amount of material conveyed and, since the elevator discharges to the separator, fluctuation in elevator power level is linked to fluctuations in the separator. Since the raw milling system must also dry material as well as grind, the air passing through the dust collector and fan will contain a significant amount of moisture and may affect the power level of the fan since the air density varies with moisture content.

4.22 Flowrates

Stone and additive materials to raw mill #2 are metered by weigh-feeders with each material passing through its own feeder. The total flowrate of all materials, 116.4 t/h, was taken as the production rate of the mill system. The approximate proportions of materials to the raw mill are 90-95% stone, 2-4% coarse sand, 0.5-1.0% fine sand, and 2% iron as mill scale.

Material conveying equipment in the mill system consists of elevators and airslides. Therefore, no other material flowrates were estimated or established directly during the field work.

4.23 Grindability

Bond grindability testing (Table 8) was performed on the stone and coarse sand because they make up the major portion of the raw mix blend and are the hardest materials involved. The Hardgrove Index was determined for these materials as well as for fine sand and iron. The Bond Index was also calculated for all four materials from the Hardgrove results.

TABLE 8 - Raw Mill - Grindability Testing

MATERIAL	GRINDABILITY		
	BOND (kWh/Ton)	HARDGROVE INDEX	BOND (Calculated)
Limestone	10.86	60	10.48
Coarse Sand	20.77	37	16.27
Fine Sand	-	55	11.34
Iron	-	75	8.55

4.24 Chemical Analysis

Analyses of the various materials in the raw mill circuit (Table 9) were obtained from the plant laboratory during the field work.

TABLE 9 - Raw Grinding - Chemical Analyses

OXIDE	STONE	COARSE SAND	FINE SAND	IRON	RAW MIX
Si	8.54	93.62	78.63	5.68	14.01
Al	2.51	0.22	8.57	1.09	2.88
Fe	0.95	0.62	3.82	90.66	2.31
Ca	46.57	2.06	1.03	2.64	42.35
S	0.24	0.06	0.01	0.09	0.21
Mg	2.24	0.55	1.24	0.75	1.70
K	0.63	0.23	1.58	0.09	0.60
Na	0.24	0.02	1.67	0.21	0.19
Loss	37.81	2.48	2.44	-	35.70

The silica (Si) content of the two sands correlates with their respective grindabilities. The coarse sand, having silica in excess of 90%, shows the higher grindability while the fine sand, with silica less than 80%, has a lower grindability, as indicated by the calculated Bond Index. The two sands make up a minor portion of the raw mix blend and, therefore, their effect on work required by the raw mill is not significant.

4.25 Particle Size Distribution

Sieve and sedigraph analyses on raw materials and raw mill circuit (Table 10) show all mill feed is -25 mm. The stone and coarse sand are similar in size range with the greatest difference in their distributions occurring in the mid-sizes. The fine sand shows a fairly narrow size distribution. The iron ranges up to 25 mm particle size but also has a significant amount of particles finer than the other raw materials.

TABLE 10 - Raw Mill #2 - Size Distributions (% Passing)

SIZE	STONE	COARSE SAND	FINE SAND	IRON	MILL DIS-CHARGE	SEPAR-ATOR REJECTS	SEPAR-ATOR FINES
25.4 mm	100	100	-	100	-	-	-
19.0	97.9	96.4	-	98.4	-	100	-
12.7	81.8	83.1	-	97.2	-	92.3	-
9.5	67.7	73.1	100	96.3	100	89.0	-
4.75	46.6	53.6	97.9	92.4	99.9	82.4	-
2.36	32.1	44.2	94.7	69.6	98.7	76.9	-
1.18	21.7	40.1	87.3	51.6	96.2	71.6	-
600 µm	14.5	37.0	70.7	42.1	89.9	63.9	100
300	9.4	24.8	39.6	36.1	75.2	48.2	99.5
150	5.9	8.5	16.6	30.7	51.1	25.9	92.7
75	3.6	3.8	7.0	24.7	35.0	13.8	79.4
45	-	-	-	-	30.5	11.7	69.6
30	-	-	-	-	27.0	11.0	62.0
20	-	-	-	-	23.5	10.0	52.5
10	-	-	-	-	17.0	7.5	37.0
6	-	-	-	-	13.0	5.5	27.0
2	-	-	-	-	6.0	3.0	12.0

The mill discharge material ranges from about 10 mm to -2 μm fraction. The presence of fresh unground stone in the separator reject stream is because stone is passed through the separator for drying before going to the mill.

The fineness target for the raw mix is 80% passing 75 μm.

4.26 Circulating Load and Separator Performance

The circulating load of the raw mill system and the separator partition curve (Fig. VI) were determined from the granulometry of the various system streams.

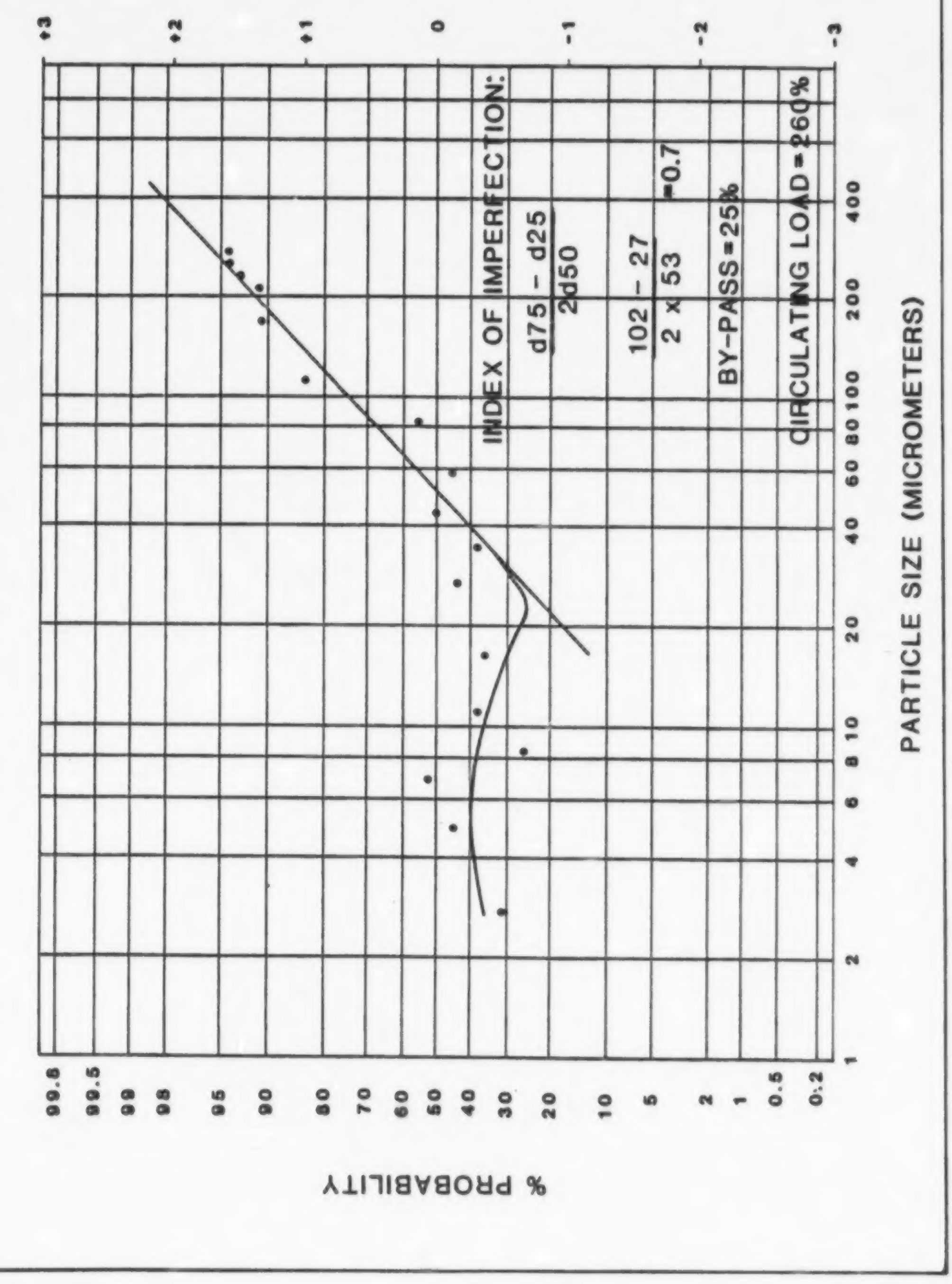
For the raw mill, allowance was made for the fact that fresh stone is present in the separator feed and reject streams. The circulating load, which is the ratio of material circulating in the system, was calculated as follows:

$$\boxed{\text{Circulating Load} = \frac{\text{Rejects} - \text{Stone}}{\text{Fresh Feed}}}$$

The reported circulating load of 260% is considered appropriate for this mill system. The electrical measurements indicate that the discharge elevator could carry a higher circulating load. However, this is not required, considering the grindability of the materials and the required fineness of the raw mix.

The separator partition curve provides a general indication of how well the separator is doing its job. The ideal classifier separates the feed material about a "cut

Figure VI - RAW MILL No.2 SEPARATOR PARTITION CURVE



point", i.e., particles above a certain size are rejected. However, in practice, the air separator is not a "perfect" classifier and actually separates particles about a "distribution" of sizes rather than a single size. The partition curve is a plot of probability of a particle of a given size ending up in the reject stream.

On the ascending part of the curve, particles are being classified according to their size. The "imperfection" of the separator is related to the slope of the curve with the "ideal" classifier having a vertical line from 0-100% probability at the "cut point" and an "index of imperfection" of zero. As the slope of the curve flattens, the index increases. On the "flat" part of the curve, particles have more or less equal probability of ending up in the rejects regardless of their size. This probability is called "by-pass" and is taken as the probability at the lowest point on the curve.

The index of imperfection and by-pass for raw mill #2 separator indicate that the separator is performing relatively well. The low by-pass of fine particles is related to the fact that coarse unground stone is in the separator feed and passes directly to rejects, thereby displacing some of the fine particles from the reject stream. The moderate circulating load also reduces feed to the separator and improves separation efficiency.

4.27 Specific Energy Consumption

The specific power consumption rate for raw mill #2 (Table 11) shows that a relatively high percentage of the total energy is required for comminution itself despite the fact that several hundred horsepower is installed on auxiliary devices; elevator, separator, and dust collector fan. However, electrical measurements indicate that the mill motor is running at capacity, while auxiliary motors are operating significantly under capacity, partly due to moderate circulating load.

TABLE 11 - Raw Grinding
Specific Power Consumption

Production Rate: 116.4 t/h

	kWh/tonne	%
Comminution	14.0	85.9
Auxiliaries	2.3	14.1
Total	16.3	100.0

4.3 Finish Grinding

4.31 Electrical Measurements

The electrical measurements for finish mill #2 (Table 12) show that the mill motor is operating at capacity. Both elevator and separator kilowatts indicate that equipment is operating steadily and within its electrical capacity.

Both precipitator and dust collector fans are well under their electrical capacity and drawing steady loads. High voltage energy to the precipitator electrodes is considered as part of auxiliary energy. The electrodes cycle through a programmed sequence of collecting and cleaning. The condition of the electrodes, material build-ups and short circuits affects the power level of the high voltage.

TABLE 12 - Finish Grinding - Measurements

		MOTOR HP	POWER OBSERVATIONS - KW		
No.	EQUIPMENT		MAX.	MIN.	AVG.
3.1	Mill	5500	4305	4301	4303
3.2	Elevator	75	50	50	50
3.3	Separator	500	306	304	305
3.4	Precipitator	100	45	45	45
	High Voltage #1		3	3	3
	#2		7	7	7
3.5	Dust Collector	50	30	30	30

4.32 Flowrates

Clinker and gypsum to finish mill #2 are metered through individual weighfeeders. The total flowrate of clinker and gypsum was taken as the production rate of the mill system. The production rate for finish mill #2 during the field work was calculated as 95 tonnes per hour. Dust flowrate from the electrostatic precipitator and cyclones had previously been determined from plant records as 15 tonnes per hour. This material is returned to the finished product and effectively by-passes the separator.

4.33 Grindability

Results of Bond and Hardgrove grindability testing (Table 13) show good agreement between measured Bond Work Index and the Bond Index calculated from Hardgrove measurements. The Hardgrove Index for gypsum indicates the most easily ground of all materials tested. The Bond test was not performed on gypsum, due to its low grindability index and also the fact that it is a minor constituent in the feed to the finish mill.

TABLE 13 - Finish Mill - Grindability Testing

MATERIAL	GRINDABILITY		
	BOND (kWh/Ton)	HARDGROVE INDEX	BOND (Calculated)
Clinker	12.01	54	11.54
Gypsum	-	98	6.71

4.34 Chemical Analysis

Chemical analyses of materials in the finish mill (Table 14) were provided by the plant laboratory.

TABLE 14 - Finish Grinding - Chemical Analyses

OXIDE	CLINKER	GYPSUM	CEMENT
Si	21.72	5.41	21.45
Al	4.47	1.50	4.43
Fe	3.58	0.50	3.50
Ca	64.00	31.50	62.78
S	1.16	43.38	3.37
Mg	2.64	0.93	2.44
K	0.93	0.15	0.98
Na	0.29	0.01	0.32
Loss	0.20	16.48	0.95

4.35 Particle Size Distribution

Clinker and gypsum mill feed (Table 15) are -25 mm and -19 mm, respectively. Both contain -150 µm material. Size distribution of various process streams in finish mill #2 system (Table 16) reveal that the separator feed is slightly coarser than the mill discharge due to finer material bypassing into the de-duster. Separator rejects are only slightly coarser than separator feed with the difference diminishing in the smaller sizes. Separator fines have a relatively narrow size distribution, while dust from the baghouse collector is very similar to separator fines in size distribution. Dust from the cyclones and precipitator is significantly coarser than separator fines or baghouse dust, particularly in the mid-sizes. The finished product, which includes separator fines plus returned dust, is somewhat coarser than the separator fines.

TABLE 15 - Finish Mill #2 Size Distributions

SIZE	% PASSING	
	CLINKER	GYPSUM
25.4 mm	100	-
19.0	99.1	100
12.7	96.5	83.4
9.5	93.7	72.7
4.75	83.3	57.8
2.36	68.2	47.9
1.18	55.2	40.4
600 µm	45.8	34.1
300	35.9	26.6
150	19.9	17.1

TABLE 16 - Finish Mill #2 Size Distributions (% Passing)

Size	Mill Discharge	Separator Feed	Separator Rejects	Separator Fines	Cyclones & Precipitator	Dust Collector	Finished Product
1.18 mm	100	-	-	-	-	-	-
600 µm	99.9	100	100	-	-	-	-
300	95.9	95.6	94.6	-	-	-	-
150	86.2	83.6	80.5	100	100	100	100
75	74.1	69.1	66.8	97.5	98.1	97.2	96.7
45	53.0	51.8	47.4	86.3	80.1	86.5	85.0
30	40.0	40.2	34.0	72.0	62.0	70.0	69.0
20	30.0	32.0	25.0	58.0	47.0	56.0	54.0
10	20.0	21.5	18.0	36.0	30.0	35.5	34.0
6	13.0	15.0	13.0	24.0	22.5	24.0	22.0
2	5.5	6.0	6.0	8.0	11.0	11.0	8.0

4.36 Internal Sampling

A total of 24 samples of material were taken from both compartments inside finish mill #2 after a crash stop (Fig. VII). Blaine and +850 µm (No. 20 sieve) testing was done. The results (Table 17) were averaged for each cut across the mill and are presented graphically in Figure VIII.

TABLE 17 - Finish Mill #2 - Internal Sampling Results

SAMPLES	AVERAGE	
	Blaine m^2/kg	+850 µm
1st Compartment		
1, 2, 3	148	6.3
4, 5, 6	137	7.8
7, 8, 9	138	7.1
2nd Compartment		
1, 2, 3	140	4.4
4, 5, 6	149	2.8
7, 8, 9	160	2.6
10, 11, 12	173	3.4
13, 14, 15	180	6.1

Figure VII - FINISH MILL No.2
INTERNAL SAMPLING PATTERN

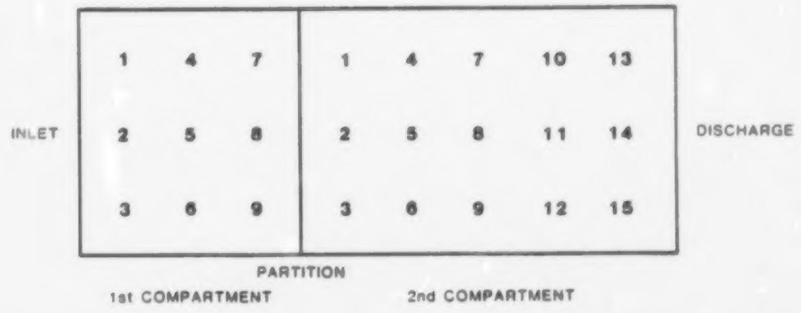
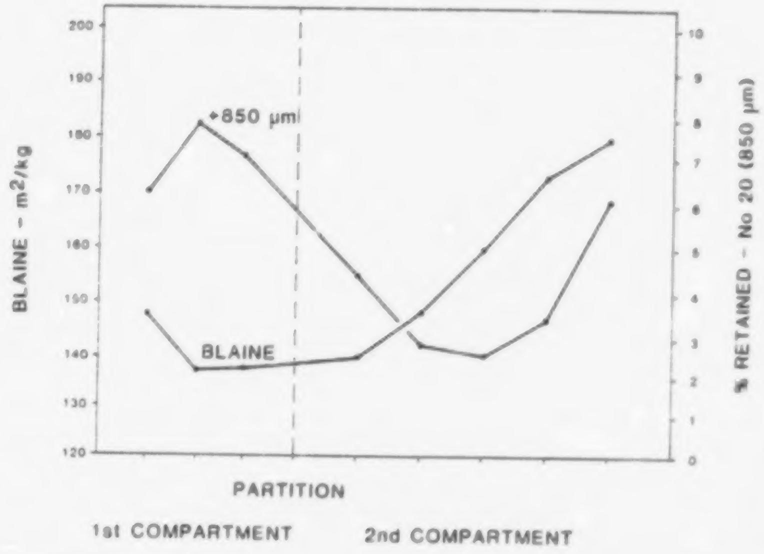


Figure VIII - FINISH MILL No.2
INTERNAL SAMPLING



The results show a drop in Blaine with a corresponding increase in +850 μm material through the first half of the first compartment. This may be the result of some reject material from the separator flushing into the mill after the crash stop.

The Blaine rises gradually through the rest of the first compartment and then rises more rapidly through the second compartment, leveling off somewhat near the end of the mill. The +850 μm material decreases through the partition and first half of the second compartment and then shows a substantial rise again toward the end of the mill.

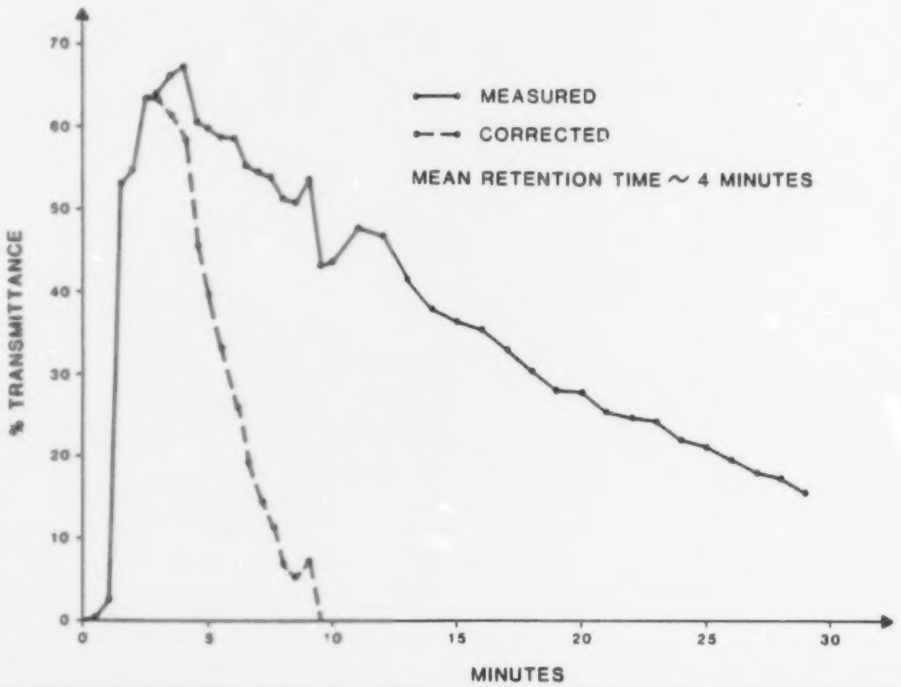
The results indicate a significant amount of coarse grinding taking place in the first compartment and first half of the second compartment with only a modest corresponding increase in fine particles. More fine grinding is shown to take place in the second compartment, as expected.

The +850 µm data confirms the poor condition of the partition between the two compartments. In a physical inspection during the internal sampling, some openings in the partition were found to be excessive and requiring repair. The result is that some coarse material passes through the partition to the second compartment and tends to accumulate near the discharge end of the mill resulting in the increase in coarse material in that area.

4.37 Residence Time Distribution

Results of residence time testing using a dye tracer are shown graphically in Figure IX. The results are plotted as % transmittance, which is proportional to tracer concentration in the sample, against time. At time zero, a quantity of tracer is introduced as a pulse to the mill inlet.

Figure IX - FINISH MILL No.2
RETENTION TIME DISTRIBUTION



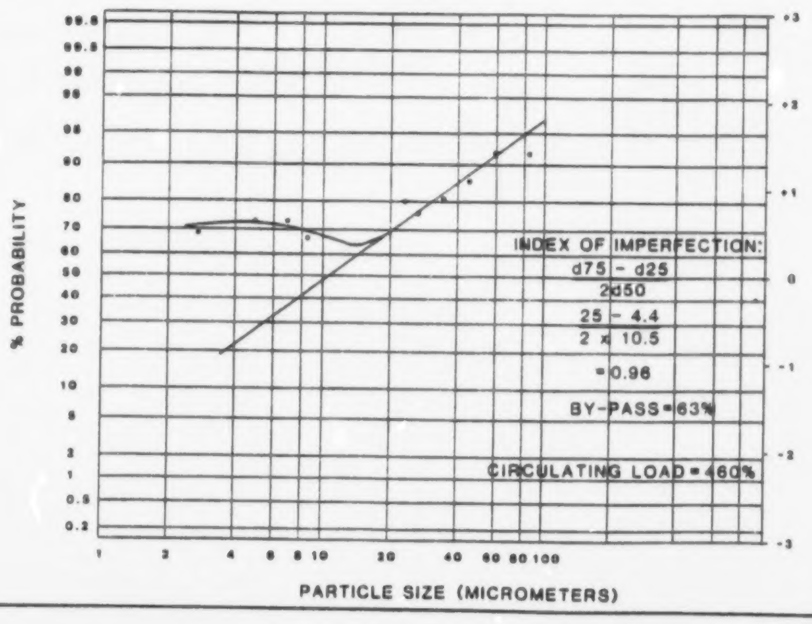
The solid curve in Figure IX depicts the results as obtained directly from the mill, with tracer concentration rising rapidly to a peak and falling off gradually as tracer is eliminated from the system. The broken curve corrects for the re-cycle of tracer back to the mill through separator rejects.

The mean residence time is taken as that point on the corrected curve, which divides the area under the curve equally. For this mill, it was calculated to be about 4 minutes. Based on past experience with the mill, this residence time is somewhat high and, is probably a result of the partition. With insufficient coarse grinding in the first compartment, a build-up of coarse material occurs in the second compartment thereby impeding the overall material flow and increasing mean residence time.

4.38 Circulating Load and Separator Performance

Circulating load and separator partition curve (Fig. X) were determined for finish mill #2.

Figure X - FINISH MILL No.2 SEPARATOR PARTITION CURVE



Allowance was made, in calculating circulating load, for 15 tph of dust from the electrostatic precipitator and cyclones which by-pass the separator and go directly to finished product. The calculated circulating load was 460%, which is considered to be relatively high and this results in elevator and separator operating at quite high power levels.

The calculated partition curve for the separator shows an index of imperfection and by-pass which are both high. The high index of imperfection, corresponding to a relatively low slope, indicates a broad distribution of sizes around which the separator is classifying the feed material. The 63% by-pass of fine particles and the index of imperfection both indicate reduced separator efficiency.

Reduced separator efficiency may be a result of separator condition and/or feed rate. In this case, visual inspection of the separator during the plant visit showed that repairs were needed to selector blades, table and diaphram. The condition of the separator tends to lead to a higher circulating load while, at the same time, the excessively high circulating load tended to impair separator efficiency. Both factors, in this case, contribute to the result shown by the partition curve.

4.39 Specific Energy Consumption

Specific power consumption (Table 18) for finish grinding is higher than raw milling. This is due to the grindability of clinker and the required fineness of the finished product.

TABLE 18 - Finish Grinding
Specific Power Consumption

Production Rate: 95 t/h

	kWh/tonne	%
Comminution	45.3	90.8
Auxiliaries	4.6	9.2
Total	49.9	100.0

The cumulative power consumption of just over 75 kWh/tonne (Table 19) for the finished product incorporates calculated specific energies as well as a number of other factors. Allowance was made for the fact that only the stone is crushed at the quarry and additive materials are ground at the raw mill. The calcination step at the kiln wastes 35-36% by weight of the raw mix as CO_2. Therefore, about 1.5 tonnes of raw mix must be ground to produce one tonne of clinker. In finish grinding, about 5% of the feed to the mill is gypsum which is not otherwise processed at the plant.

Auxiliaries consume 12% of the total, with most auxiliary energy being required for classification and dust collection.

TABLE 19 - Finish Product
Cumulative Consumption

Comminution 88.8% - Auxiliaries 11.2%

	kWh/tonne	%
Crushing	1.9	2.4
Raw Grinding	24.2	31.9
Finish Grinding	49.9	67.7
Total	76.0	100.0

5. CONCLUSIONS

The St. Constant plant, which is a typical Portland cement manufacturing facility, has an energy intensive process. The largest energy consumer is pyroprocessing but electrical energy requirements for crushing and grinding and associated equipment is high. This results from the need to reduce large lime rock to a fine powder for the kilns and also to grind the resulting clinker nodules of higher grindability than the stone, to an even finer product. Also, the loss of over a third by weight of raw mix during calcining further increases the energy expenditure to produce a unit amount of finished product.

The unit energy expenditure for primary crushing of limestone was found to be quite modest. Also, with the crushing production rate curtailed by wet conditions at the time of the visit, the results may be somewhat higher than would be realized under dry, ideal conditions. The reduction of the stone at the primary crusher to a relatively coarse -19 mm results in the low unit energy requirement.

The grinding and associated energy requirement at the raw mill was much greater than primary crushing. This is due mainly to the fineness of the raw mix. Also, the presence of a small amount of high grindability silica sand contributes to the raw mill system energy requirement.

Analysis of separator performance according to granulometries of various system streams showed that the circulating load and separator efficiency are good. The separator partition curve has a good index of imperfection with low by-pass of fine particles. The low by-pass is also related to the use of the separator to dry the limestone entering the system. A significant portion of the rejects is composed of fresh, coarse stone. The relatively low circulating load of the raw mill system enhances separator efficiency. Generally, the raw mill #2 system was found to be performing well.

The unit electrical energy requirement of finish mill #2 was determined to be relatively high. This is due to the hardness of the clinker which comprises the majority of the mill feed and also the fineness specification of the finished product.

Inspection of mill internals as well as results generated from internal material sampling and retention time distribution, all indicate the unsatisfactory condition of the partition between compartments. Some excessively large gaps were observed in the partition and internal sampling results show a build-up of relatively coarse material in the second compartment, indicating that this material is entering the second compartment before being sufficiently ground in the first. The mean retention time was also found to be high due to the hold-up of the coarse material in the second compartment.

The circulating load of the system was found to be quite high. The calculated partition curve corresponded to a high index of imperfection and a high by-pass of fine particles to rejects. The results indicate low separator efficiency which is partly the result of high circulating load. Inspection of the separator during the field work showed the need for internal repair work, especially to selector blades and table.

The cumulative energy calculated to produce the finished cement takes into account specific comminution and auxiliary energies of the various departments, as well as other factors. The unit consumption is substantial and, considering the productive capacity of the plant, the potential for energy conservation is significant. Dust collection and classification are the main consumers of auxiliary energy in this process.

APPENDIX

INDUSTRY REVIEW

GENERAL INFORMATION

Cements are finely powdered mixtures of inorganic compounds which, when mixed with water, undergo a chemical (hydration) reaction and harden; those which harden under water are termed hydraulic. The "Portland" cement now used worldwide in quantities of about 80 million metric tons annually is produced from raw materials comprised of some of the earth's most abundant elements. Cement when mixed with water, fine aggregate (sand) and coarse aggregate (gravel or crushed stone) forms concrete.

The origin of modern cements was the lime-based materials used by the Greeks and Romans who developed lime cements and mortars from calcined limestones. The calcined product, when mixed with reactive or pozzolanic materials such as volcanic ash, had binding properties superior to the gypsum plasters developed by the early Egyptians.

Further development of these simple cements occured between the first century B.C. and the third century A.D.; little further advancement took place until the late 18th century when it was observed that when some argillaceous limestones were calcined they gave a hydraulic cement and the naturally occuring mix of the appropriate materials became known as cement stone or rock. By modern standards, these products were only lightly calcined so as not to be too greatly densified by sintering and therefore easily ground.

Joseph Aspdin, who obtained a patent in 1824, is usually regarded as the inventor of modern Portland cement. His product, made by burning chalk with clay in a lime kiln and grinding the sintered product (clinker), was considerably inferior to the present day material. Two fundamental developments have improved on the early product: the introduction of gypsum, added when grinding the clinker, to act as a set retarder (c. 1890) and the use of higher burning temperatures to allow the production of higher lime content silicates which are necessary for more rapid strength development in concrete. Improvements were aided by the gradual replacement of vertical shaft kilns with the rotary kiln and the introduction of the ball mill.

World cement production has levelled off over the last three years at about 760 million tonnes per year.

TABLE 1 - World Production Summary

(Quantities in 1,000 metric tons)

YR.	EUROPE	USSR*	AFRICA	MIDDLE EAST	U.S. & CANADA	ASIA	AUSTRALIA	TOTAL WORLD
Production								
'82	276,550	124,000	29,600	41,400	141,550	258,750	6,400	761,100
'81	283,050	127,169	28,268	35,432	151,200	256,100	7,050	761,200
'80	290,600	124,800	25,475	30,177	153,800	250,888	5,560	765,500
Imports								
'82	8,350	254	12,850	31,700	7,900	12,250	550	73,600
'81	8,400	200	5,752	38,498	7,400	10,650	550	71,250
'80	9,300	523	8,542	11,569	8,700	11,452	120	49,683
Exports								
'82	40,750	2,221	2,348	1,202	4,200	22,750	400	71,650
'81	39,750	2,735	1,898	1,402	4,900	20,500	350	68,800
'80	34,600	3,245	1,831	2,435	5,450	17,252	247	61,815
Apparent Consumption								
'82	244,250	122,033	39,200	69,250	142,700	249,350	6,600	751,350
'81	251,350	124,634	35,654	63,696	151,350	248,000	7,250	757,300
'80	265,100	122,078	30,809	50,288	154,100	245,721	5,780	751,798
Apparent Consumption per capita (kg)								
'82	465	452	107	572	225	110	290	184
'81	472	466	98	564	242	111	320	189
'80	515	460	92	823	252	241	395	386

Source: World Statistical Review, December 1983, published by CEMBUREAU, The European Cement Association, Paris, France

* U.S.S.R. figures also included in Europe summary.

Exports in 1982 were in the order of 73 million tonnes, of which 54% came from 5 countries, Spain, Japan, Greece, South Korea and Turkey which have located large scale cement plants at deep water ports specifically for the export market.

TABLE 2 - Top World Cement Exporters

(Quantities in 1,000 metric tons)

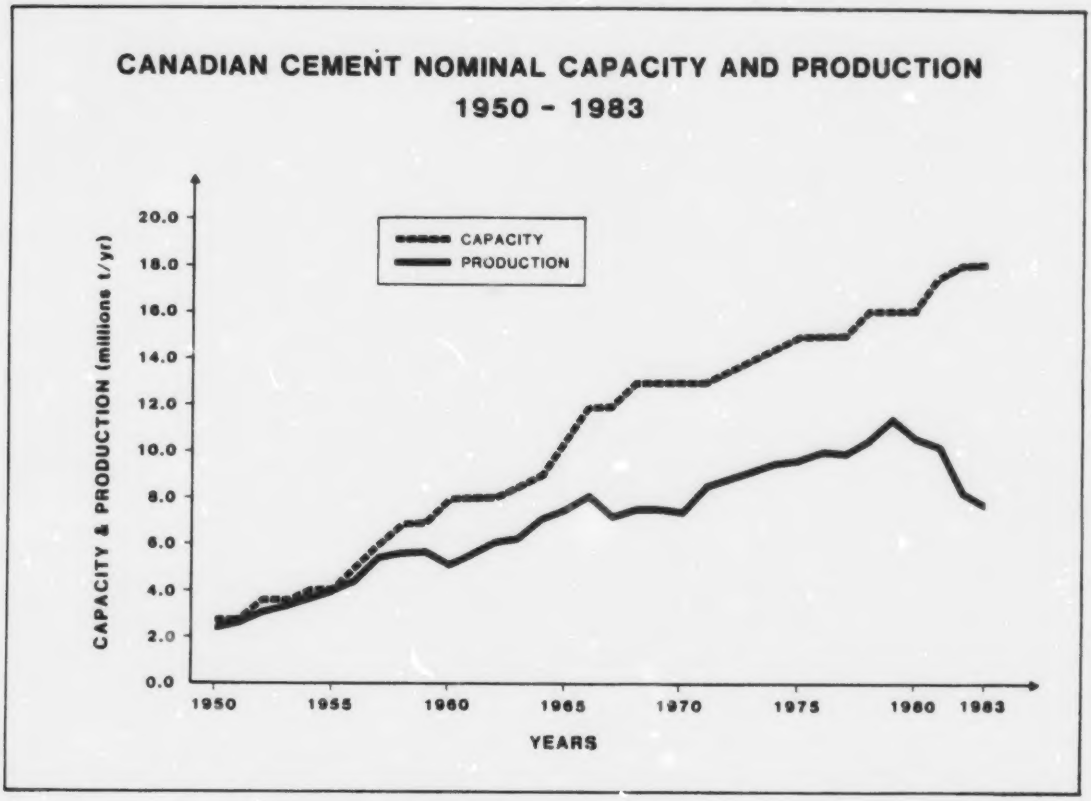
COUNTRY	VOLUME
Spain	11,835
Japan	11,173
Greece	6,887
South Korea	5,598
Turkey	4,186
France	3,059
Romania	3,000
Taiwan	2,683
U.S.S.R.	2,221
Canada	2,160
German Federal Rep.	2,159

Source: Lafarge Coppée

The Canadian Industry

Use of Portland cement in Canada began in 1887[3]. Although cement was imported initially, domestic production began in 1889. At that time, there were four cement plants in Canada located in the Montreal-Ottawa-Toronto area. Over the next few decades, the capacity to produce Portland cement grew rapidly, with several companies becoming involved and constructing new facilities. The resulting oversupply and competition created an unstable situation for the industry with little or no profits being made. This was resolved by consolidating the industry under the Canada Cement Company in 1909. Following this early expansion, growth of the cement industry in Canada was moderate until after the Second World War when, again, consumption of cement increased rapidly.

Expansion of capacity and replacement of old facilities with more efficient plants continued until the early 1980's when the economic recession severely reduced the demand for cement, leaving the industry with considerable excess capacity. This situation is expected to persist for a number of years.


CANADIAN CEMENT NOMINAL CAPACITY AND PRODUCTION 1950 - 1983

Source: Canada Cement Lafarge Ltd.

The relatively low value to weight ratio of cement has led to plants being sited as near as possible to their markets so that transportation costs can be minimized. The production capacity, as shown in Table 3, is spread across the country serving local markets by truck, rail and boat where possible and also supplying markets in the northern U.S. states.

TABLE 3 - Canadian Cement 1983 Capacity and Location

Company	Number of Kilns	Clinker Capacity	Grinding Capacity
ATLANTIC			
Canada Cement Lafarge Ltd	4	743	910
North Star Cement Ltd	1	130	250
QUEBEC			
Canada Cement Lafarge Ltd	2	910	950
Miron	2	838	1000
St. Lawrence Cement	6	1599	1625
Ciment Québec	1	840	449
ONTARIO			
Canada Cement Lafarge Ltd	3	1321	1612
Lake Ontario Cement	4	1442	750
St. Lawrence Cement	3	2000	1986
St. Mary's Cement	5	1593	1590
PRAIRIES			
Canada Cement Lafarge Ltd	5	1635	2113
Genstar Cement	6	1723	1597
BRITISH COLUMBIA			
Canada Cement Lafarge Ltd	3	635	796
Genstar Cement	1	950	1042
TOTAL	45	16,359	16,670

Source: Portland Cement Association

Involvement of most cement producers does not end with the manufacture of cement. Companies tend to be integrated into the concrete and related construction material industries. Cement companies supply ready-mix concrete, aggregates, and pre-formed concrete products. Because the primary consumption of cement is in the construction industry, sales for the cement industry is directly linked to the level of construction activity.

Research by the cement industry is aimed at improving the efficiency of the manufacturing process as well as increasing the uses of cement and concrete in various applications. The cement manufacturing process is energy intensive with over 80% of the energy being consumed at the pyroprocessing stage. Research is being carried out to improve thermal efficiency and to find cheaper energy sources. Many plants are now set-up to burn several fuels depending on process requirements and fuel costs. Research is being conducted on raw and finish grinding to optimize power consumption.

The Cement Manufacturing Process

The manufacture of Portland cement is essentially the production of calcium silicates from limestone and a silicate material such as clay or shale. The reaction is accomplished by pyroprocessing (heat-treating) a finely-pulverized mixture of the correctly-proportioned quantities of limestone and shale.

The chemical reactions involved are summarized in Table 4.

TABLE 4 - Chemistry of the Pyroprocess

Limestone ($CaCO_3$) $\xrightarrow{900°C}$ $CaO + Co_2$ gas

Clay silicates, Aluminates, etc. 900°C $SiO_2 + Al_2O_3 + Fe_2O_3$

$2\ CaO + SiO_2 \longrightarrow$	1200°C	Ca_2SiO_4	approximately 75% of clinker
$Ca_2SiO_4 + CaO \longrightarrow$	1400°C	Ca_3SiO_5	
$3CaO + Al_2O_3 \longrightarrow$	1300°C	$Ca_3Al_2O_6$	approximately 20% of clinker
$Ca_3Al_2O_6 + CaO + Fe_2O_3 \longrightarrow$	1300°C	$Ca_4Al_2Fe_2O_{10}$	

The net reaction is strongly endothermic (requiring heat). The iron and alumina compounds form liquid phases during the clinkering process and thereby act as a flux.

There are two main cement manufacturing processes:

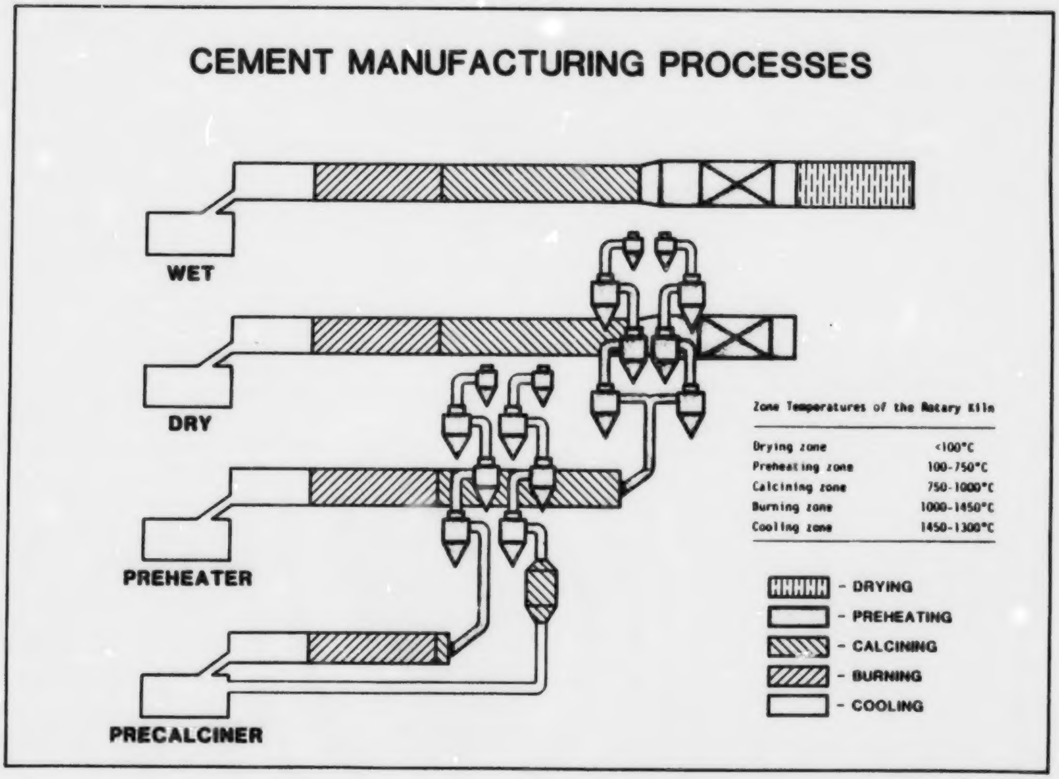
- **wet**, where the raw materials are ground to give a slurry of 30-35% water, which is pumped to the kiln. Because of its thermal inefficiency, this process is gradually being phased out;
- **dry**, where the raw feed is ground and fed to the kiln dry.

Variations of the dry process are the preheater and precalciner technologies, in which the raw material is preheated and precalcined in suspension before entering the kiln. The approximate heat consumption of the various processes is as follows.

PROCESS TYPE	GJ/t CLINKER
Wet	5.0 - 6.0
Long Dry	3.6 - 4.6
Preheated Precalciner	3.5 - 4.3

The pyroprocess by which clinker is formed involves temperatures in the material of up to 1450°C. To achieve this, a flame temperature greater than 2700°C is needed. These high temperatures are normally generated by burning gas, oil or pulverized coal.

The location of the different zones in the kiln is shown in the diagram below for the different systems. The kilns shown are all for the same production rate, so the figure clearly illustrates the decrease in physical size as development makes the manufacturing process more efficient.



Zone Temperatures of the Rotary Kiln

Drying zone	<100°C
Preheating zone	100-750°C
Calcining zone	750-1000°C
Burning zone	1000-1450°C
Cooling zone	1450-1300°C

Source: Della M. Roy, J. Educational Modules for Materials Science & Engineering 1981, Vol. 3, No. 4, p. 631.

Chemical and Physical Characteristics

The performance of a cement is controlled by a combination of physical and chemical characteristics.

The most important physical characteristic of cement is its fineness; the more finely ground, the more reactive the cement is; the more reactive, the greater the strength development. The data below shows the relation of fineness, as measured by the Blaine permeability method, and strength development.

PRODUCT	BLAINE M^2/Kg	COMPRESSIVE STRENGTH M Pa at (days)			
		1	3	7	28
Normal Portland	374	-	23.1	29.3	37.4
High Early Strength	550	24.6	35.2	-	47.7

The four major chemical compounds and their principal properties are summarized in Table 5.

TABLE 5 - Properties of the Major Constituents of Portland Cement Clinker

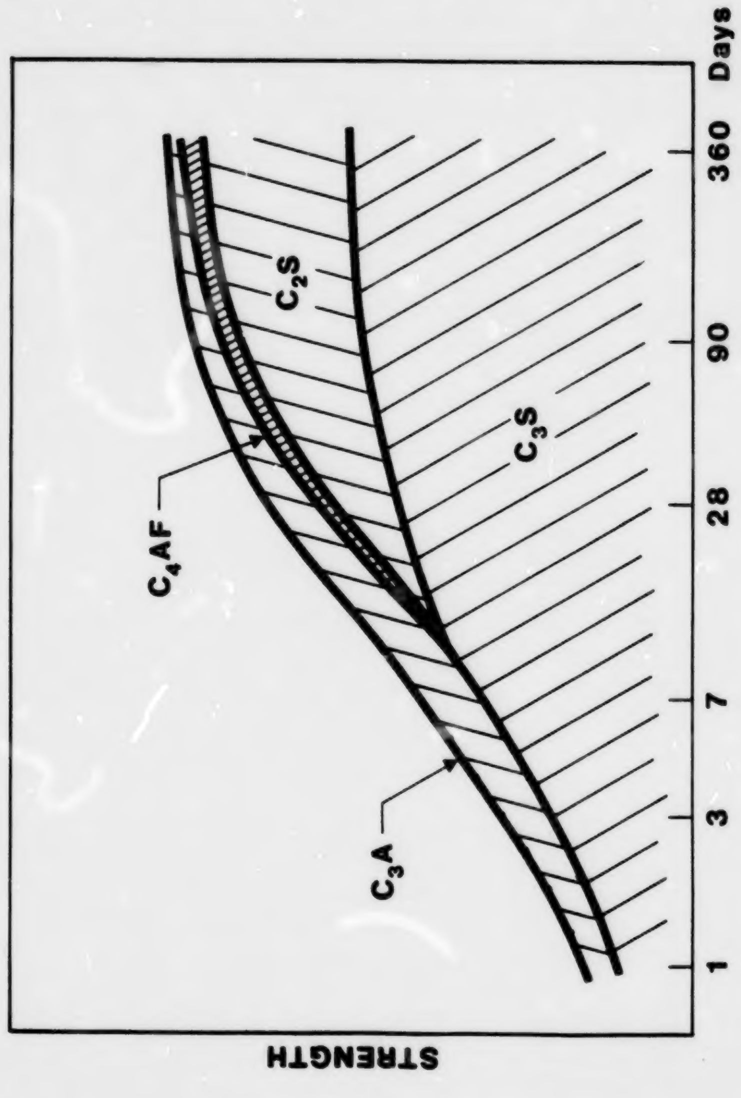
CLINKER CONSISTS OF:	C_3S +	BC_2S +	C_3A +	C_4AF
Idealized chemical composition	Tricalcium silicate, $3CaO.SiO_2$	Dicalcium silicate, $2CaO.SiO_2$	Tricalcium aluminate, $3CaO.Al_2O_3$	Tetracalcium aluminoferrite, $4CaO.Fe_2O_3.Al_2O_3$
"Impure" phase equivalent	Alite	Belite	C_3A-alkali solid solution	Ferrite phase solid solution
Rate of hydration	Rapid (hours)	Slow (days)	Instantaneous	Very Rapid (minutes)
Heat of hydration	Medium: $\sim$500 J/g	Low: $\sim$250 J/g	Very High: $\sim$850 J/g	Medium: $\sim$420 J/g
Remarks	Characteristic constituent of Portland cements.		Unstable in water, sensitive to sulphate attack.	Imparts to the cement its characteristic grey color.

* Note the special formula abbreviation scheme used universally by cement chemists. Each oxide (a mole of CaO, Al_2O_3, Fe_2O_3, SiO_2, SO_3) is represented by a letter C, A, F, S, or $\overline{S}$, respectively. The latter, SO_3, is added usually as gypsum, $C\overline{S}H_2$, to the clinker to make the cement, and is important in controlling hydration of C_3A and C_3S.

Most of the strength of cement is from hydration of the di- and tricalcium silicates. The latter contributes to early strength development while the former contributes after about 10 days. The role of tricalcium aluminate and tetracalcium aluminoferrite are not well defined but are believed to act as shown in the graph overleaf.

TYPICAL CEMENT COMPOSITION

55% C_3S, 20% C_2S, 10% C_3A, 10% C_4AF



Chemical Requirements

The chemical requirements for cement tend not to be very strict, since it is known that cements with quite different chemical compositions may have suitable physical behaviour. Generally, the chemical requirements simply specify the maximum amounts of certain impurity oxides, such as MgO, SO_3, Na_2O, and K_2O. In addition, for certain types of cement such as low heat cements or sulphate resistant cements, there may be limitations on the contents of the four major cement constituents (C_3S, C_2S, C_3A, C_4AF).

Physical Properties

The **fineness** of cement can have a considerable effect on the behavior of cement during hydration. Of greatest importance, the rate of hydration increases with increasing fineness, leading to both a higher rate of strength gain and a higher rate of evolution of heat. In addition, finer particles will be more completely hydrated than coarser particles, because hydration takes place at the surface of the cement particles, forming a zone of reaction products which hinders further hydration.

There are two parameters that may be used to describe fineness: the specific surface of the cement particles (i.e., the summation of the surface areas of all of the cement grains in 1 kg of cement), and the particle size distribution. The general practice is to use only the specific surface area (Blaine) to quantify cement fineness, even though cement with quite different particle size distributions may have the same specific surface area.

Physical Properties of Cement Pastes (Cement + Water)

Consistency: Most commonly, the normal consistency is defined in terms of the Vicat apparatus, in which the penetration of a special needle into the cement paste under a given weight is determined. This test is a measure of the plasticity of the cement paste.

Time of setting: Two setting times are generally defined; initial set, which indicates that the paste is beginning to stiffen and final set which indicates that the paste has hardened to the point at which it can sustain some load.

Unsoundness refers to excessive volume change in the cement paste after setting. Any appreciable expansion, however slow, will result in cracking of the concrete. Unsoundness may be caused by the hydration of MgO or of free lime or by the reactions of C_3A with gypsum (sulfate expansion). Because these reactions are very slow, accelerated tests must be used to check for possible unsoundness.

The **heat of hydration** is defined as the amount of heat evolved during the setting and hardening of cement at a given temperature, measured in J/g of unhydrated cement.

Physical Properties of Mortars (Cement + Sand + Mortar)

Since the properties of mortars are also dependent on their consistencies, some specifications are written in terms of consistency. The consistency of mortars is expressed as mortar flow, defined in terms of the increase in diameter of a cone of mortar subjected to a specified jolting on a flow table.

Since mortar strength increases with curing time, the test age must be specified. Normally, minimum allowable strengths are specified for rapid hardening and low heat of hydration cements, respectively. Strengths are normally measured in either compression or flexure.

Compressive strength is by far the most common measure of strength required by cement specifications. It is normally measured at 3, 7 and 28 days.

Flexural strength is a measure of the tensile strength in bending, is particularly common in Europe, though its use is increasing in North America as well.

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THE GYPSUM INDUSTRY

ENERGY CONSERVATION IN THE INDUSTRIAL
MINERALS PROCESSING SECTOR - COMMINUTION

(Phase I - Plant Studies)

Work on this Project was conducted by
Canada Cement Lafarge Ltd.,
under the auspices of the
Canada Centre for Mineral and Energy
Technology; Energy, Mines and Resources, Canada

DSS File Number: 23SQ.23440-2-9016A
DSS Contract Serial Number: OSQ82-00228

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APPENDIX - Industry Review

1. General Information
2. Product Characteristics
3. Quality Criteria

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1. INTRODUCTION

Cooperating Company:

Domtar Incorporated

Plant Location:

Caledonia, Ontario

The report introduces first the company that cooperated in the study. A description follows of the comminution processes monitored during the field work at the company's plant. The measurements made and results obtained are then reported and discussed and conclusions drawn.

For readers who are not familiar with the gypsum industry, an appendix entitled "Industry Review" is added. Details concerning data collection and field work, as well as other raw data or measurements, are available in working papers.

2. COMPANY DESCRIPTION

2.1 Operational Groups

Domtar Incorporated is a Canadian company with head office in Montreal. The company is organized into five operational groups including pulp and paper, construction materials, box and packaging, chemical products, and energy resource investments. Each operational group is further divided into various divisions, dealing in a particular area of interest. Divisions of the construction materials group include Canadian and U.S. gypsum operations, insulation products, masonry products and others.

Manufacture of gypsum products is in the hands of two divisions, one in Canada, the other in the U.S. Processing plants in the U.S. are located in California and Washington.

The Canadian gypsum products division has plants in British Columbia, Alberta, Manitoba, Ontario, Quebec, and Nova Scotia. Gypsum mining activities are located in Gypsumville, Manitoba, and Caledonia, Ontario.

2.2 Products

The plant at Caledonia manufactures two types of products: wallboard and plaster. Wallboard consists of re-hydrated gypsum set in a preformed shape. Plaster consists chiefly of ground, calcined gypsum containing some additives.

Additives to the gypsum during wallboard manufacture modify the setting rate as well as some properties of the finished product. The board is formed in 1.2 meter width and cut in various lengths to meet requirements. Of the two products manufactured at Caledonia, gypsum wallboard comprises the greater volume.

2.3 Raw Materials

The gypsum for the Caledonia plant occurs in a seam of about 4.6 meter thickness although the mined thickness varies from 2.1 to 2.7 meters.* It is fine-grained and white to light brown, interlayed with brown dolomite and, to some extent, with grey dolomite shale. A 30 cm shale layer above the roof of the mine is relatively impervious to water and serves to prevent excessive surface drainage into the mine.

The gypsum is mined using the room and pillar method, leaving about 20 percent of the gypsum in place for support and grade control. The rooms are of 6.1 to 6.7 meter width with 9.8 meter centers.

The ore is blasted, loaded and conveyed to the primary crushing system located in the mine. The mine has been in operation since 1952 and is accessed by an inclined 4.1 x 3.0 meter shaft. The seam is at a depth of 23 meters.

The ore contains about 72 percent gypsum with impurity being mainly dolomite. However, no beneficiation of the ore takes place in the process at Caledonia.

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* Gypsum in Ontario, G.R. Guillet; Ontario Dept. of Mines; Industrial Mineral Report No. 18 (1964).

3. PROCESS DESCRIPTION

3.1 Gypsum Process Flow

The process line at the Caledonia gypsum plant (Fig. I) uses a combination of equipment and processes that are common to many industries as well as some that are unique to the gypsum industry itself. Crushing, drying and grinding of the relatively soft ore is done with conventional equipment. However, the low temperature calcining technique applied at Caledonia is unique to the gypsum industry.* The technique of "sandwiching" calcined gypsum slurry between two layers of paper for rapid re-hydration and setting to form a gypsum "board" forms the background for the usefulness of gypsum in the construction industry.

The value of gypsum as a mineral rests chiefly in its ability to give up and re-gain associated water molecules in its crystal structure. The process is temperature dependant but high temperatures are not required. In its partially de-hydrated calcined form the gypsum is an easily handled powder. When mixed with water, the material re-gains water and "sets up" to form a fairly rigid mass, harder than the original ore.

The objective of the process is to calcine gypsum ore to form plaster or stucco, then re-hydrate in a slurry and allow it to harden after being formed into a board. This objective is accomplished at Caledonia in three stages. The ore is first processed through a primary crushing circuit. At the plant, the ore is dried of surface moisture,

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* The Canadian Gypsum Industry, R.K. Collings; Mineral Processing Div., Department of Mines and Technical Surveys, Ottawa (1959).

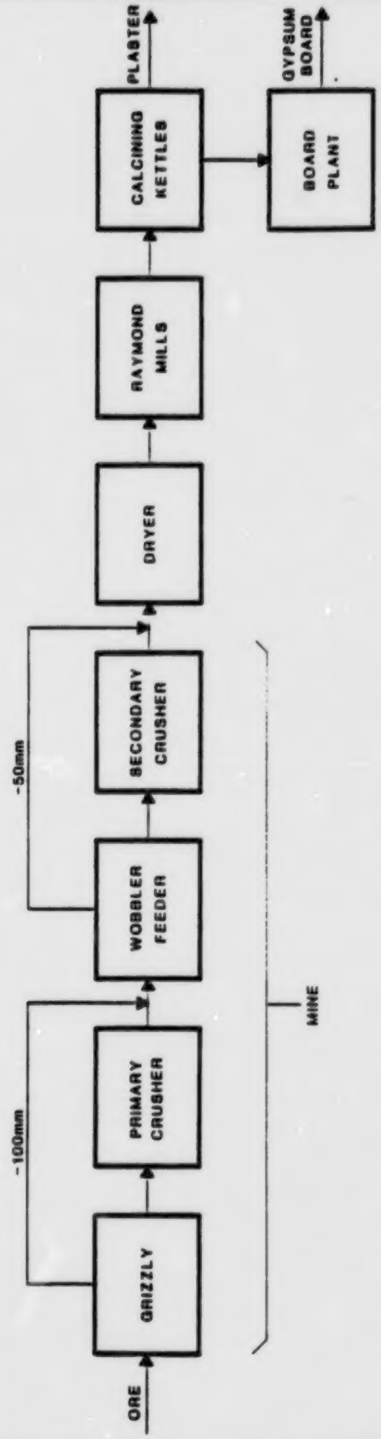


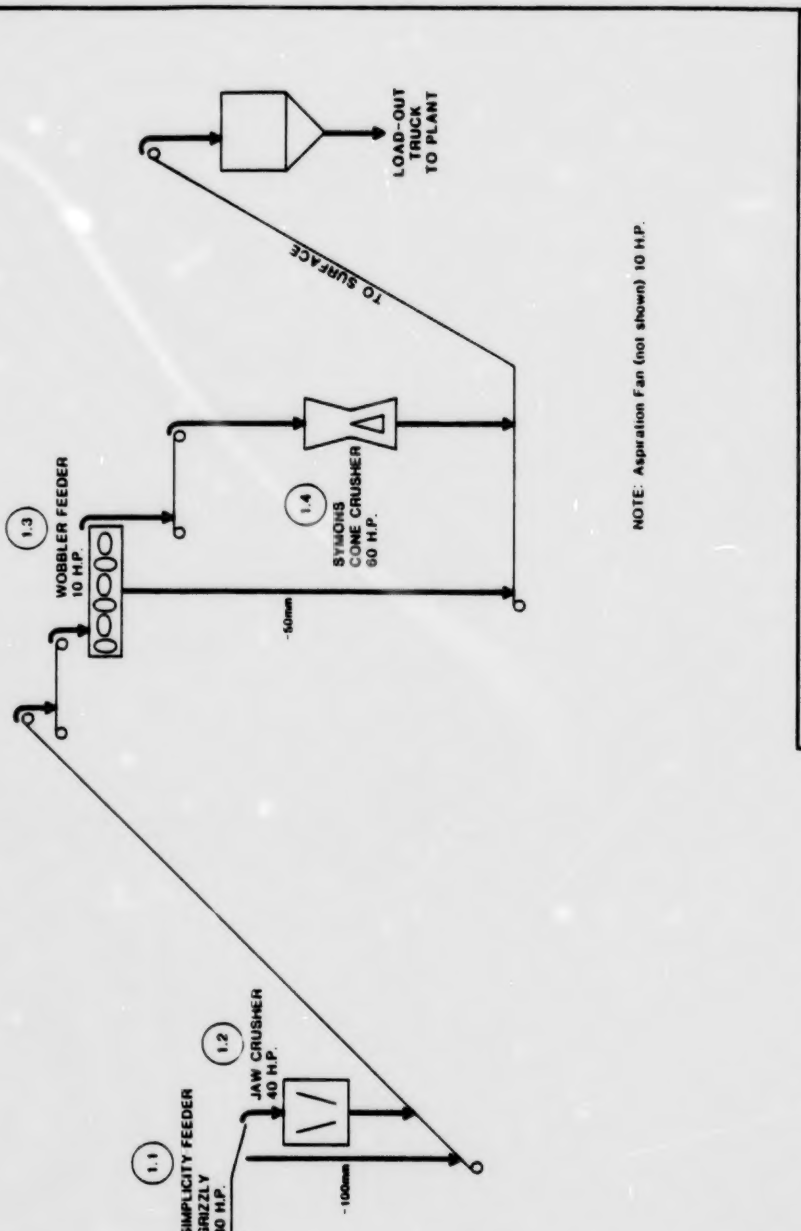
Figure I - PROCESS FLOW SHEET
DOMTAR GYPSUM DIVISION
CALEDONIA, ONTARIO

ground and calcined. The final stage is the production of gypsum board in a continuous process. The product is then palletized for shipment.

3.2 Gypsum Crushing

Gypsum rock is transferred from the mine face by conveyor to the primary crushing circuit (Fig. II) which is located in the main conveyor way. The rock is held temporarily in a hopper which discharges to a vibrating grizzly feeder. The feeder, powered by a 30 HP motor, removes minus 10 cm material. The oversize material from the grizzly is fed to a 40 HP jaw crusher where it is reduced to a maximum size of 15 cm. The undersize from the grizzly and the primary crusher product is conveyed some distance along the conveyor way to the secondary crusher operation.

At the secondary crusher, the gypsum ore discharges from the belt conveyor to a Wobbler feeder. This device consists of a series of rotating shafts of roughly oval cross-section. The combined rolling and eccentric motion created by the feeder serves to move the material over the feeder while agitating it, allowing fine material to drop between the shafts. The Wobbler, which is powered by a 10 HP motor, removes minus 5 cm material from the ore. The oversize from the Wobbler feeder discharges to a belt feeding the material to a Symons cone crusher. The 60 HP secondary crusher reduces the material to 7.5 cm maximum size. The undersize from the Wobbler feeder and secondary crusher product discharge to a common belt conveyor which transfers the material to the surface through the inclined access tunnel. The gypsum is held in bins at the mine site from which it is loaded into trucks and hauled to the processing plants.



NOTE: Aspiration Fan (not shown) 10 H.P.

CANADA CEMENT LAFARGE LTD.
MONTREAL

FIGURE II
GYPSUM CRUSHING
FLOW DIAGRAM

DRAWN FGM
DATE 01/03/84
CHECKED DCS
DATE 20/09/84

PLANT CONSTRUCTION MATERIALS
DOMTAR-CALEDONIA, ONT.

PROJECT No. 20010

The entire crushing operation is relatively dust-free, requiring no dust collection equipment except for a 10 HP aspiration fan at the vibrating grizzly feeder to the jaw crusher.

The equipment list for the crushing circuit is presented in Table 1.

TABLE 1 - Gypsum Crushing Equipment List

EQUIPMENT		MOTOR*	
No.	TYPE/MAKE/MODEL	HP	AMPS
1.1	Simplicity Feeder - Grizzly	30	32
1.2	Jaw Crusher	40	41
1.3	Wobbler Feeder	10	10
1.4	Symons Cone Crusher	60	66
1.5	Aspiration Fan	10	11

* All motors 550 volts

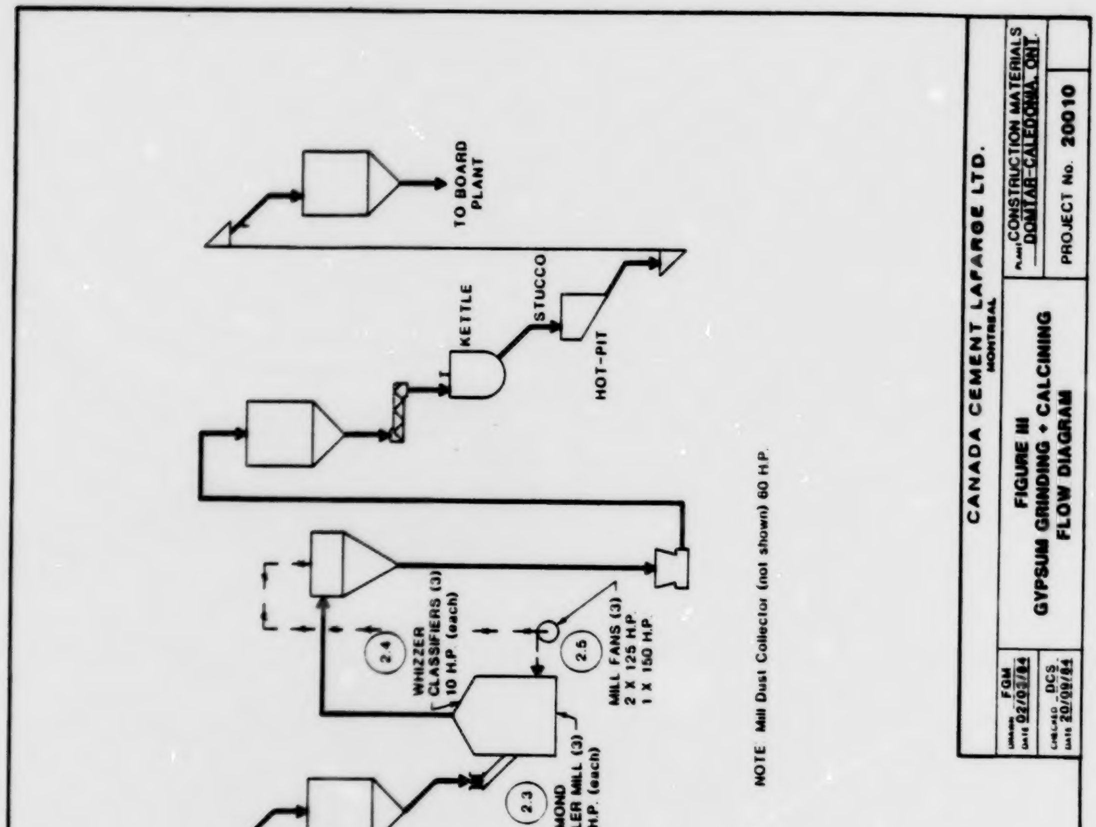
3.3 Drying, Grinding and Calcining (Plant 325)

Crushed ore is stored in a holding bin at the plant (Fig. III) then conveyed by belt to a rotary gas-fired dryer powered by a 50 HP motor. The material passes co-current with the hot gases. The dryer discharges through a screw conveyor and elevator to the feed bins for the Raymond mills. Draft through the dryer is provided by a 60 HP I.D. fan pulling air through a baghouse. The collected dust is returned to the dryer discharge.

Dried ore is metered by rotary feeders into 3 Raymond 6000 roller mills, each powered by a 150 HP motor. The material is carried from the grinding zone to a 10 HP variable speed whizzer classifier located in the upper part of the mill by draft from an external fan. Feed rate to the mills is by on-off control of the rotary feeder which regulates the pressure drop across the mill. The whizzer returns oversize material to the grinding zone. Product specification material is entrained out of the mill by draft to a cyclone which removes it from the airstream and sends it to a pump. Air from the cyclone is returned through the fan to the bottom of the mill. Two mills are equipped with 125 HP fans; the other has a 150 HP fan. Raymond mill product is ground to 95-97 percent passing 150 μm.

Calcination is a batch process involving 5 gas-fired kettles. Their capacities range from 9 to 18 tonnes. Each kettle is equipped with an internal agitator to mix the gypsum during calcining.

During a typical cycle, a kettle is filled with ground gypsum, the burner is fired and the material temperature raised to 160°C. The fire is shut off and the material rapidly dumped into a hot pit where it cools. The calcined material is then transferred by screw conveyor and elevator to a holding bin and thereafter to the board making plant.


ORE
2.2
I.D. FAN
60 H.P.
2.1
ORE DRYER
50 H.P.
2.3
RAYMOND
ROLLER MILL (3)
150 H.P. (each)
2.4
WHIZZER
CLASSIFIERS (3)
10 H.P. (each)
2.5
MILL FANS (3)
2 X 125 H.P.
1 X 150 H.P.
KETTLE
STUCCO
HOT-PIT
TO BOARD
PLANT
NOTE: Mill Dust Collector (not shown) 60 H.P.
CANADA CEMENT LAFARGE LTD.
MONTREAL
FIGURE III
GYPSUM GRINDING + CALCINING
FLOW DIAGRAM
PLANT CONSTRUCTION MATERIALS
DOMTAR-CALEDONIA, ONT.
PROJECT No. 20010
DRAWN FGM
DATE 02/03/84
CHECKED DCS
DATE 20/09/84

The equipment list for drying and grinding is presented in Table 2.

TABLE 2 - Grinding and Calcining Equipment List

EQUIPMENT		MOTOR*	
No.	TYPE/MAKE/MODEL	HP	AMPS
2.1	Ore Dryer (Gas)	50	48
2.2	Dryer I.D. Fan	60	57
2.3	Raymond Roller Mill 6000 (3)	150	140
2.4	Whizzer Classifier (3)	10	11
2.5	Mill Fan (2)	125	116
	(1)	150	145
2.6	Mill Dust Collector	60	57

* All motors 550 volts

3.4 Gypsum Board Plant

The board plant (Fig. IV) is made up of a number of steps including forming, setting, cutting, drying, and palletizing, all integrated into one continuous production line.

Two rolls feed paper simultaneously, a layer for each side of the board. Stucco, along with controlled proportions of water and additives, are metered into a pin mixer where a uniform slurry is produced. This mixture is sandwiched between the two layers of paper and fed into a board-forming unit, which consists of two forming rolls and auxiliary equipment for turning and gluing the edges of the paper. The board leaves the machine with well-defined surfaces and edges. The temperature of the stucco is closely controlled to optimize the setting time of the gypsum when mixed with water.

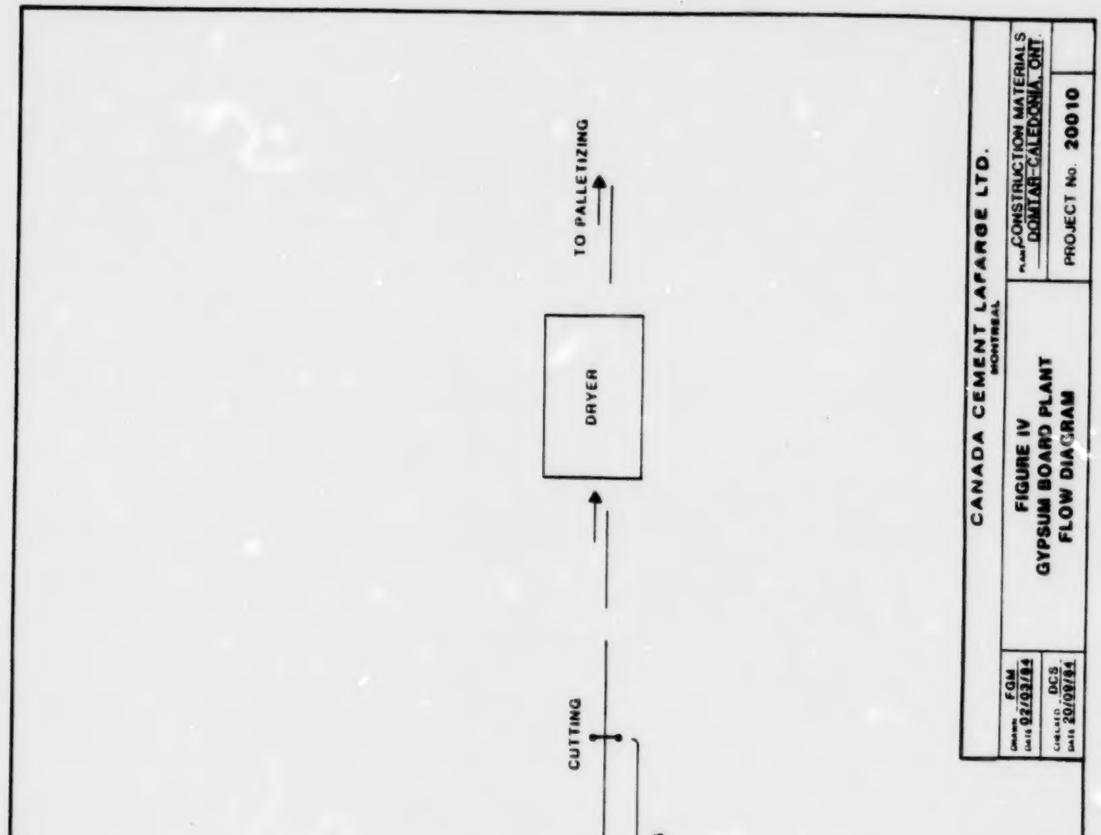


FIGURE IV
GYPSUM BOARD PLANT
FLOW DIAGRAM

The board from the forming unit is maintained in a continuous length, supported and carried along by a roller conveyor system. During this time setting of the gypsum layer occurs. The board is then cut by rotary cutters to lengths varying from 1.8 to 3.6 meters. Despite the fact that some water is required in the gypsum crystal structure for setting, sufficient excess water is added to the stucco to require drying. This is accomplished by the use of a gas fired, multi-deck unit. The boards take more than half an hour to pass through the dryer in which the temperature ranges from 170°C at the inlet to 90°C at the discharge end. The boards are then stacked and palletized for storage and shipment.

The process is monitored continuously at key points and, should defects in board or paper occur, corrections are made immediately to ensure a quality product.

4. RESULTS AND DISCUSSION

4.1 Gypsum Crushing

4.11 Electrical Measurements

Measured power demand of comminution and auxiliary equipment in the primary crushing circuit (Table 3) were calculated from measured volts, amp and power factor readings. Comparison of measured power levels with rated horsepower shows that the circuit is operating well under capacity.

An exception is the aspiration fan drive at the feeder-grizzly which was operating well above its rated power. This motor operates a small un-dampered fan drawing dust from the area around the feeder and venting it into an abandoned area of the mine. There is no dust collection device associated with it.

TABLE 3 - Primary Crushing Measurements

		MOTOR HP	POWER OBSERVATIONS - kW		
No.	EQUIPMENT		MAX.	MIN.	AVG.
1.1	Simplicity Feeder	30	8.5	8.5	8.5
1.2	Jaw Crusher	40	10.1	10.1	10.1
1.3	Wobbler Feeder	10	2.1	2.1	2.1
1.4	Cone Crusher	60	29.7	29.7	29.7
1.5	Aspiration Fan	10	10.4	10.4	10.4

Electrical measurements in the primary circuit were taken during a period of steady operation at peak throughput.

4.12 Flowrates

Personnel at the mine indicated that the mine produces, on average, about 2350 tonnes of crushed gypsum ore per day in two eight-hour shifts. However, to calculate specific power consumption for the circuit from the electrical measurements, it was desirable to use the instantaneous or peak flowrate at the time the measurements were made. This was estimated from the final product belt. Using a belt speed of 91.5 m/min, a material bed width of 30.5 cm and average depth of 9 cm, and a crushed gypsum bulk density of 1370 kg/m^3, a flowrate of 210 t/h was established and used to calculate energy consumption. A production of 2350 tonnes in 16 hours implies a utilization factor of about 70%. This allows for start-up time, which is significant, and down time for repairs and shift changes.

Flowrates through individual crushers were also estimated. About two-thirds of the incoming circuit feed bypassed the jaw crusher giving a flowrate through the crusher of 70 t/h. The split at the Wobbler feeder before the cone crusher was about 50:50 giving a cone crusher flowrate of 105 t/h.

4.13 Size Distributions

Most size distribution data pertaining to the crushing circuit is given in Table 4. The feed material to the circuit was observed to have a maximum size of about 300 mm with most of the material being -150 mm. The primary crusher product, a mixture of jaw crusher discharge and grizzly undersize, has been reduced to 150 mm, with a significant proportion of -50 mm.

TABLE 4 - Domtar Gypsum Crushing Circuit Size Distributions (% Passing)

mm	CIRCUIT FEED[1]	PRIMARY CRUSHER PRODUCT[1]	SECONDARY CRUSHER FEED[1]	CIRCUIT PRODUCT[2]
300	100			
150	80	100	100	
100		85	93	
75			80	100
50	40	60	20	90
38				80
25				60
19				50
12.5				40
4.75				20

[1] Estimated
[2] Sieve Analysis

The secondary or cone crusher feed, the Wobbler feeder oversize, has most of the -50 mm material removed. The circuit product, a mixture of cone crusher discharge and Wobbler feeder undersize, has been reduced to -75 mm with most of the material smaller than 50 mm. The circuit product size data was obtained by sieve analysis. A more detailed distribution is given in 4.2 as Raymond mill feed.

4.14 Grindability Testing

An attempt was made to determine the Bond Work Index on a sample of crushed gypsum ore from the Caledonia mine. However, it was found that the material tended to coat the grinding media and impede the flow of material from the test mill. Therefore the Bond Work Index could not be determined. The Hardgrove Index was found to be 61. The Bond Index of 10.32 kWh/Ton was calculated from the Hardgrove result. The calculated Bond Index appears to be high for gypsum. However, the Caledonia ore contains significant impurities which may influence the test results.

4.15 Specific Energy Consumption

Energy consumption data for the primary crushing circuit (Table 5) shows the total specific energy of the circuit to be low with comminution energy making up 2/3 of the total.

Since primary processing of mineral ores generally involves drying of surface moisture, the specific energy for drying itself was calculated (Table 6) from the measurements of dryer and I.D. fan drives (Table 8). The flowrate through the dryer was taken to be the same as the combined production rate of the Raymond mills (41 t/h).

The drying energy consumption was added to the primary circuit specific energy to arrive at the consumption for dry ore preparation (Table 7).

The comminution consumption accounts for just over 1/10 of the cumulative specific energy to this point.

The low energy consumption of the primary circuit itself reflects the degree to which the material is reduced in size, and the relative ease with which it is crushed.

TABLE 5 - Primary Crushing - Specific Power Consumption

	kWh/tonne	%
Comminution	0.19	66
Auxiliaries	0.10	34
Total	0.29	100

TABLE 6 - Drying - Specific Power Consumption

	kWh/tonne
Consumption	1.17

TABLE 7 - Dry Ore Preparation
Specific Power Consumption

	kWh/tonne	%
Comminution	0.19	13
Auxiliaries	1.27	87
Total	1.46	100

4.2 Gypsum Drying, Grinding and Calcining

4.21 Electrical Measurements

Measured power levels in the gypsum drying and grinding circuit (Table 8) reveal both dryer drive and I.D. fan motors to be operating at about 60% of their rated power under steady load.

TABLE 8 - Drying and Grinding Measurements

		MOTOR HP	POWER OBSERVATIONS - kW		
No.	EQUIPMENT		MAX.	MIN.	AVG.
2.1	Dryer	50	21.7	21.7	21.7
2.2	I.D. Fan	60	26.3	26.3	26.3
2.3	Raymond Mill #1	150	135	135	135
	#2	150	118	118	118
	#3	150	115	115	115
2.4	Whizzer #1	10	3.7	3.7	3.7
	#2	10	3.3	3.3	3.3
	#3	10	4.5	4.5	4.5
2.5	Fan #1	125	95.2	95.2	95.2
	#2	150	96.3	96.3	96.3
	#3	125	103	103	103
2.6	Dust Collector	60	17.6	17.6	17.6

The Raymond mill motors were found to be operating steady at near full rated amps. Combined with a relatively high observed power factor (0.9), all three mill motors were at or exceeding their rated power output. Similarly the fan motors were observed to have high power factors and were operating at 85-90% of their rated capacity.

The whizzer classifier drives were observed to be operating at about half their capacity. The single dust collector fan for the Raymond mill circuit was operating at under half its capacity. All motors in the drying and grinding circuit were operating with little or no fluctuation in power.

4.22 Flowrates

The production rate of the circuit obtained from plant records was 41 t/h.

4.23 Size Distributions

Particle size analyses pertaining to mill circuits (Table 9) were determined for feed and product. The feed stream corresponds to the final product from the primary crushing circuit. This material is generally referred to in the plant as being -50 mm.

The product from the mill circuit, prior to calcining, has been reduced to -425 µm. The in-plant target for the Raymond mill product is 95-97% passing 150 µm.

Particle size analysis revealed that this material was slightly below the target. An interesting point concerning the data on the mill product is the large proportion of superfine material. Nearly half the sample was -10 µm. It is apparent that a significant amount of over-grinding is taking place in the Raymond mills.

TABLE 9 - Domtar Raymond Mill Circuit Size Distributions (% Passing)

SIZE	FEED	PRODUCT
75 mm	100	
50	90.5	
25	61.9	
12.5	40.0	
4.75	22.4	
1.18	11.4	
425 µm		100
300	5.7	98.8
150	3.8	93.0
106		84.5
75		78.3
45		75.5
30		69.5
20		63.0
10		48.0
6		35.0
2		13.5

Due to the design of the Raymond mill, oversize material from the whizzer classifier is returned to the grinding zone in an internal stream. Therefore, this recirculating material could not be sampled to determine the particle size distribution or obtain further information on the whizzer performance or magnitude of the circulating load.

4.24 Specific Energy Consumption

The total specific consumption for the Raymond mill circuit (Table 10) is relatively low at 17 kWh/t. Comminution consumption accounts for just over half of the total energy. This is a typical result for a Raymond mill since the mill and fan motors are rated about equally. The slightly greater comminution energy is accounted for by the heavier loading of the mill motors compared to the fan and whizzer drives.

TABLE 10 - Gypsum Grinding
Specific Power Consumption

	kWh/tonne	%
Comminution	8.98	53
Auxiliaries	7.92	47
Total	16.9	100

Cumulative energy consumption for gypsum crushing and grinding (Table 11) is shown for stucco. The reported consumption allows for a yield of 89% at the calcining step since most of the chemically associated water in the gypsum is driven off. The comminution consumption has decreased to exactly half of the total as a result of the low proportion of specific energy in the primary circuit made up by comminution alone.

TABLE 11 - Stucco
Cumulative Power Consumption

	kWh/tonne	%
Comminution	10.3	50
Auxiliaries	10.3	50
Total	20.6	100

Specific energy consumption for comminution and auxiliaries for finished gypsum board was not expressed as consumption per unit weight since board is generally measured in terms of surface area. The total thermal consumption for gypsum board production is of the order of 3.4 GJ/100 m^2. The specific electrical energy consumption for crushing and grinding was converted to equivalent thermal energy for thermal generation (1 kWh from 10.5 MJ) and expressed as a percentage of total thermal consumption (Table 12). Since the stucco is re-hydrated to make board, the calcining yield factor is removed from the calculation. The results show that, even in terms of equivalent thermal energy, crushing and grinding consumption is about 2.5% of the total energy required. Most of the energy is needed for drying the board after forming.

TABLE 12 - Gypsum Board
Cumulative Power Consumption

(% of total equivalent thermal energy)

	%
Comminution	2.5
Comminution & Auxiliaries	5.0

5. CONCLUSIONS AND RECOMMENDATIONS

Specific electric energy consumption for crushing and grinding of gypsum at Caledonia is relatively low, relating to other industrial minerals in general and in relation to the total equivalent thermal energy required per unit of finished gypsum board. The low consumption is attributed to the grindability of gypsum and the fact that fine grinding is not required.

The power consumption of the primary crushing circuit shows this part of the process to be operating quite efficiently during peak throughput with the average consumption probably being somewhat higher as a result of start-up time and interrupted production. The electrical measurements indicated that the crushers, particularly the jaw crusher, had some spare productive capacity which might be used by feeding a coarser material to the circuit and maximizing the utilization factor of the circuit.

The total energy for dry ore preparation is comparable to that of other minerals and is relatively low; about 1.5 kWh/t. Although the crushed ore is referred to as being -50 mm, some larger material was observed at between 50 and 75 mm.

The Raymond mill product was found to fall slightly below the target of 95% passing 150 µm. However, the amount of -10 um material in the ground product was significant. The superfine material may be evidence of over-grinding possibly due to a high circulating load inside the Raymond mills.

Overall, power consumption in crushing and grinding is small. Any improvement in specific energy would be expected to have minimal effect on the overall manufacturing cost.

APPENDIX

INDUSTRY REVIEW

GENERAL INFORMATION

The Mineral and its Processing

The term "gypsum" is used as a commercial and generic term for all calcium sulfate materials. Gypsum is a hydrated calcium sulfate ($CaSO_4$, $2H_2O$) commonly found in close association with anhydrite which is the anhydrous calcium sulfate ($CaSO_4$). These minerals generally occur as sedimentary rocks associated with limestone, shale or clay. Most gypsum is white to grayish white, but impurities can change the colour of the rock and final products.

Gypsum was used by the Egyptians and by the Romans as a plaster for important buildings and remains, to this day, a major material for the building industry, mainly in prefabricated products. It is produced in 62 countries around the world. The largest producer is the U.S.A. which accounted for about 15% of the world production in 1981. It is followed by Canada with about 10% of the world production. The other main producers are: France, U.S.S.R., Spain, United Kingdom, West Germany, China, Mexico, and Italy. Typical gypsum production volumes are shown in Table 1.

TABLE 1 - Gypsum - USA, Canada, World Production 1978-82[1]
(in thousands of tonnes)

	1978	1979	1980	1981	1982*
U.S.A.	13,509	13,200	11,227	10,430	10,160
Canada	8,074	8,098	7,336	7,800	7,530
World	70,276	74,400	71,500	77,094	74,389

* estimated

In 1978, the world reserves were estimated at about two billion tonnes; 350 million tonnes in the United States, 410 million tonnes in Canada and 900 million tonnes in Europe.

Gypsum is mined from open pit and underground mines. Most crude gypsum is used as mined, but it is possible to beneficiate some low grade ores.

Processing of crude gypsum depends on the end use. Gypsum for cement is crushed to minus 38 mm, plus 9.5 mm and gypsum for agricultural or filler use is pulverized to 150 μm or finer. For the other uses, the first stage is primary crushing using jaw or gyratory crushers to reduce the ore to about 150 mm. Then ore is shipped to processing plants where it is reduced to about 50 mm by roll crushers or hammer mills. Ground ore is dried in rotary driers and then reduced to about 150 μm by hammer mills and roller mills. The next step is calcination, usually in large batch kettles. Modern plants tend to grind and calcine in a single stage.

Calcination can also be done prior to grinding. In that case, plants use rotary kilns where coarse feed is continuously calcined. Then the calcined gypsum is ground to about 150 μm in roller, ball, or tube mills.

Calcination is a very important step which aims to release three quarters of the chemically combined water of gypsum ($CaSO_4, 2H_2O$) to obtain the hemihydrate ($CaSO_4, \frac{1}{2}H_2O$). Calcined gypsum ("stucco") mixed with water is commonly called "plaster of Paris".

The calcined gypsum is manufactured in a plaster plant or in a board plant. Plaster plants use tube mills where calcined gypsum is reground to get a flake-like grain. Different additives such as accelerators or retarders and other ingredients are mixed with the stucco to meet consumers requirements.

In board plants additives including "land plaster" (ground gypsum) are mixed with the stucco to form a slurry which is conveyed through two rolls of absorbent paper, cut and dried to be manufactured into wallboards and laths.

A special high temperature treatment in rotary kilns converts crushed gypsum to insoluble anhydrite. This product is manufactured into a harder and stronger plaster called Keene's cement.

By-product gypsum, which is a chemical product obtained from industrial processes such as acidulation of phosphate rock, hydrofluoric acid, citric acid and desulfurization of stack gas in thermal power plants, accounts for 25% of world gypsum consumption. No by-product gypsum is used in Canada.

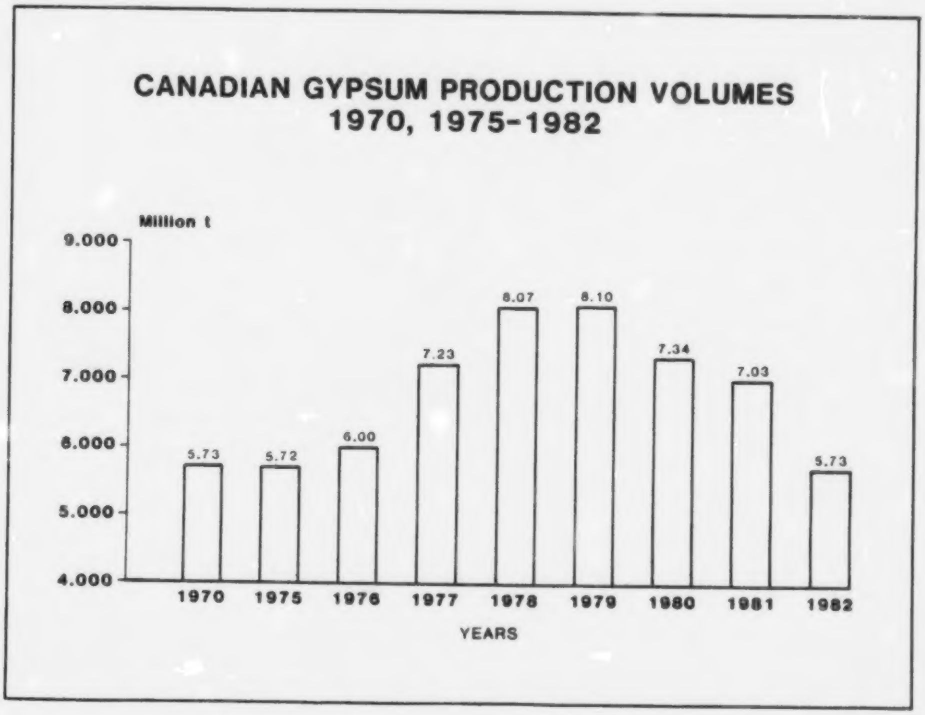
The Canadian Industry

The first production of gypsum in Canada was recorded in Nova Scotia in about 1760. The principal gypsum producing province is Nova Scotia which contributed about 75% of the Canadian production in 1982. The other main sources are located in British Columbia, Ontario, Newfoundland, and Manitoba. A breakdown of the production by province in 1981 and 1982 is shown in Table 2.

TABLE 2 - Gypsum Production - Breakdown by Province 1981-82[2]

	1981		1982	
	'000 t	$ Million	'000 t	$ Million
Nova Scotia	4,993	29.45	4,290	27.7
British Columbia	685	5.8	415	5.5
Ontario	613	5.2	506	4.5
Newfoundland	512	3.8	416	3.3
Manitoba	202	2.4	88	1.5
New Brunswick	20	87,000 $	10	52,000 $
TOTAL	7,025	46.8	5,726	42.6

In 1980, about 67% of Canadian production was exported to the United States as crude gypsum. The remainder was used domestically. Canadian production volumes in 1970 and from 1975 to 1982 are shown in the diagram below.



Source: Canadian Minerals Yearbook 1982, EMR Canada.

Gypsum mining and gypsum products operations in 1981 are shown in Tables 3 and 4.

TABLE 3 - Canada, Summary of Gypsum Mining Operations, 1982[1]

PROVINCE - COMPANY	LOCATION	REMARKS
Newfoundland		
Flintkote Holdings Ltd.	Flat Bay	Open-pit mining of gypsum
Nova Scotia		
Little Narrows Gypsum Co.	Little Narrows	Open-pit mining of gypsum & anhydrite
Georgia-Pacific Corp.: Bestwall Gypsum Div.	River Denys	Open-pit mining of gypsum
Fundy Gypsum Co. Ltd.	Wentworth & Miller Creek	Open-pit mining of gypsum & anhydrite
National Gypsum (Canada)	Milford	Open-pit mining of gypsum
Domtar Inc.	MacKay Settlement	Open-pit mining of gypsum
New Brunswick		
Canada Cement Lafarge Ltd.	Havelock	Open-pit mining of gypsum used in cement manufacturing
Ontario		
Canadian Gypsum Co. Ltd.	Hagersville	Underground mining of gypsum
Domtar Inc.	Caledonia	Underground mining of gypsum
Westroc Industries Ltd.	Drumbo	Underground mining of gypsum
Manitoba		
Domtar Inc.	Gypsumville	Open-pit mining of gypsum
Westroc Industries Ltd.	Amaranth	Open-pit mining of gypsum
British Columbia		
Western Gypsum Ltd.	Windemere	Open-pit mining of gypsum
Canada Cement Lafarge Ltd.	Falkland	Open-pit mining of gypsum

Source: Energy, Mines, and Resources Canada

TABLE 4 - Canada, Summary of Gypsum Products Operations, 1982[1]

PROVINCE - COMPANY	LOCATION	REMARKS
Newfoundland		
Atlantic Gypsum Ltd.	Corner Brook	Gypsum products manuf.
Nova Scotia		
Domtar Inc.	Windsor	Gypsum plaster manuf.
Quebec		
Canadian Gypsum Co Ltd	Montreal	Gypsum products manuf.
Canadian Gypsum Co Ltd	St-Jérôme	Gypsum products manuf.
Domtar Inc.	Montréal	Gypsum products manuf.
Westroc Industries Ltd	Ste-Catherine d'alexandrie	Gypsum products manuf.
Ontario		
Canadian Gypsum Co Ltd	Hagersville	Gypsum products manuf.
Domtar Inc.	Caledonia	Gypsum products manuf.
Westroc Industries Ltd	Clarkson	Gypsum products manuf.
Manitoba		
Domtar Inc.	Winnipeg	Gypsum products manuf.
Westroc Industries Ltd	Winnipeg	Gypsum products manuf.
Saskatchewan		
Genstar Corporation	Saskatoon	Gypsum products manuf.
Alberta		
Domtar Inc.	Calgary	Gypsum products manuf.
Westroc Industries Ltd	Calgary	Gypsum products manuf.
Genstar Corporation	Edmonton	Gypsum products manuf.
British Columbia		
Westroc Industries Ltd	Vancouver	Gypsum products manuf.
Domtar Inc.	Vancouver	Gypsum products manuf.
Genstar Corporation	Vancouver	Gypsum products manuf.

Source: Energy, Mines, and Resources Canada

Market Outlook

Gypsum is abundant throughout the world but is used mainly in industrialized countries. Crude gypsum is a low cost commodity and the consumer's cost is closely dependent on transportation costs. This explains why some plants are operated by U.S. companies which find it more cost effective to import gypsum from Canada rather than mining U.S. deposits. In the same way, Canadian provinces such as Ontario, Alberta, and British Columbia used to import wallboard from U.S.A., but these imports have greatly declined during the last few years.

In 1982, U.S. demand was weak and Canadian gypsum production was down 20% from 1981. Such a drop can be explained by a slump in the construction industry in North America.

In the long run, consumption of prefabricated gypsum products is expected to increase steadily while building and industrial plasters should decline. While an increased utilization of fertilizer could result in a greater use of gypsum as a soil conditioner in future, the major developments should occur in the area of building materials despite competition from other materials substitution, such as plywood and particle boards, cement, concrete, and steel.

Most of the commercial gypsum is 85% to 95% pure as produced. The main impurities are limestone, shale, or clay. The amount of impurities which can be tolerated depends upon the type of impurity, the final product and the competitive situation. The chemical analyses of pure gypsum and anhydrite are shown in Table 5.

TABLE 5 - Chemical Analysis of Pure Gypsum - Anhydrite[3]

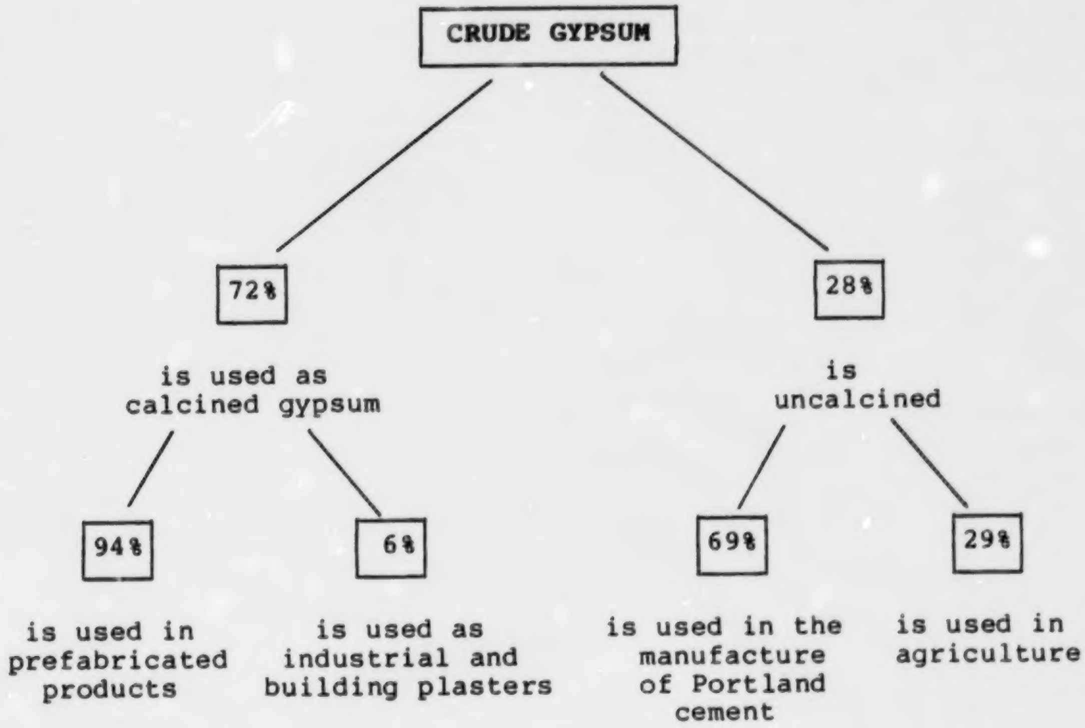
	Pure Gypsum	Anhydrite
Combined water	20,9%	-
Sulfur trioxide (SO_3)	46,6%	58,8%
Lime (CaO)	32,5%	41,2%

Gypsum is slightly soluble in water, soluble in dilute hydrochloric acid and insoluble in sulfuric acid. Uses of crude gypsum, also called "land plaster", are listed below:

- Manufacture of Portland cement. Gypsum acts as a retarder to control the setting of concrete.
- Filler in paint or paper manufacture.
- Substitute for salt cake in glass manufacture.
- Soil conditioner.

The breakdown by uses in U.S.A. in 1981 was as follows:

FIGURE 2 - Gypsum - Breakdown by Uses - U.S.A. 1981


CRUDE GYPSUM
72%
is used as calcined gypsum
28%
is uncalcined
94%
6%
69%
29%
is used in prefabricated products
is used as industrial and building plasters
is used in the manufacture of Portland cement
is used in agriculture

The tests to monitor quality, according to the different products, are listed in Table 6.

TABLE 6 - Gypsum Products - Tests to Monitor Quality

PRODUCT	TESTS
● Gypsum	● Chemical Analysis ● Fineness
● Gypsum Plasters (incl. Keene's Cement)	● Chemical Composition ● Fineness ● Time of setting ● Compressive Strength
● Lath, Wallboard, Sheeting	● Composition ● Flexural Strength ● Size-Weight-Finish
● Gypsum Tile or Block	● Composition ● Compressive Strength ● Dimensions

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REFERENCES

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THE LIME INDUSTRY

ENERGY CONSERVATION IN THE INDUSTRIAL MINERALS PROCESSING SECTOR - COMMINUTION

(Phase I - Plant Studies)

Work on this Project was conducted by
Canada Cement Lafarge Ltd.,
under the auspices of the
Canada Centre for Mineral and Energy
Technology; Energy, Mines and Resources, Canada

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APPENDIX - Industry Review

1. General Information
2. Product Characteristics
3. Quality Criteria

REFERENCES

1. INTRODUCTION

Cooperating Company:

Domtar Incorporated

Plant Location:

Joliette, Quebec

The report introduces first the company that cooperated in the study. A description follows of the comminution processes monitored during the field work at the company's plant. The measurements made and results obtained are then reported and discussed and conclusions drawn.

For readers who are not familiar with the lime industry studied, an appendix entitled "Industry Review" is added. Details concerning data collection and field work, as well as other raw data or measurements, are available in working papers.

2. COMPANY DESCRIPTION

Domtar Inc. was approached as a representative lime producer whose comminution operations could be monitored. The lime plant located at Joliette, Quebec was selected to conduct the data collection campaign.

2.1 General

Domtar Inc. is one of the largest Canadian industrial groups operating over 70 manufacturing plants distributed in Canada and the United States of America. The total sales of the company were close to $1.7 billion in 1982.

The large number of activities and products sold by this company are divided among five operating groups which can be listed in decreasing importance as follows:

1 - Pulp and Paper : 50% of sales
2 - Construction Materials : 19% of sales
3 - Box and Packaging : 15% of sales
4 - Chemical Products : 16% of sales
5 - Energy Resources Investments

2.2 The Lime Division

Domtar's Lime Division is the largest lime producer in Canada. In 1982, with sales of $29 million, it accounted for about 20% of total sales in Canada. In terms of production volume, the capacity of Domtar is estimated at 600,000 tonnes per year representing about 18% of Canadian capacity.

The production capacity is from two plants, one in Ontario and one in Quebec.

The plant located at Joliette, Quebec, has a capacity of 300,000 tonnes per year and produces quicklime and hydrated lime as well as a variety of limestone products essentially for construction and agricultural uses.

The Joliette plant consists of three rotary kilns, built at different times in the sixties and the seventies. Two kilns are of a conventional type, and one is a grate-kiln system (Allis Chalmers-Lepol).

During the survey period (April 1983), only kiln #3 which has an annual capacity of 150,000 tonnes was operating.

2.3 Products Marketed

Typical specifications of the plant's products are listed in Tables 1 and 2.

Almost half of the lime production is sold to the steel industry where it is used as a flux. The main requirements of this market are a low sulfur content and the absence of fines. The lime is thus a typical pebble material having a size gradation specification of minus 50 mm and plus 4.75 mm. It is made by feeding the kiln with a limestone having a coarse and narrow size gradation (12.5 x 50.0 mm) and by screening twice, the minus 6.3 mm fraction, first after cooling and before storage, secondly before loading into a truck for shipping. The sulphur specification is set at 0.08% maximum.

TABLE 1 - Domtar - Joliette Lime Plant Products Marketed

LIME PRODUCT	SIZE GRADATION	CHEMICAL CRITERIA
1) Hi-Calcium Quicklime (Steel Making)	100% minus 50.0 mm	% S=0.08 max.
2) Hi-Calcium Quicklime	100% minus 19.0 mm 8% minus 4.75 mm	% S=0.2 or 0.08 max.
3) Hi-Calcium Quicklime	100% minus 6.7 mm 80% minus 2.36 mm 45% minus 600 µm	% S=0.1
4) Hi-Calcium Pulverized Quicklime (-3.35 mm)	100% minus 4.75 mm 98% minus 3.35 mm 85% minus 1.18 mm 70% minus 600 µm	% S=0.1
5) Hi-Calcium Hydrated Lime	96% minus 300 µm 92% minus 150 µm 86% minus 75 µm 80% minus 45 µm	Nil

TABLE 2 - Domtar - Joliette Lime Plant Products Marketed - Limestone Products

1) Aggregate Stone

% Passing	6.3 x 12.5 mm	12.5 x 19.0 mm	19.0 x 31.5 mm	31.5 x 50.0 mm
50.0 mm				100
38.1 mm			100	61
25.0 mm		100	68	3
19.0 mm	100	86	14	1
12.5 mm	99	18	2	
9.5 mm	56	3		
4.75 mm	3			

2) Chemical Stone - 96% $CaCO_3$ (0 x 6.3 mm)
100% minus 6.7 mm
72% minus 3.35 mm
40% minus 1.00 mm
16% minus 150 µm

3) Agricultural Limestone - 92% $CaCO_3$
100% minus 3.35 mm
80% minus 850 µm
41% minus 150 µm

4) Pulverized Limestone
99% minus 150 µm
85% minus 75 µm
70% minus 45 µm

The second major market for the Joliette plant is in non-ferrous metallurgical uses, particularly in the aluminum industry for production of alumina from bauxite and in the copper and zinc industries.

The third important market is in pulp and paper where lime plays a major role as a causticizing agent in the sulfate process. It is also used in this industry for other purposes, such as the preparation of bleaching liquors, a dissolver and a neutralizing agent.

Fourthly, the water treatment sector represents an important and growing market. Here, lime is used chiefly for softening, purification and neutralization.

For these markets (non-ferrous metals, pulp and paper, water treatment), higher fineness will generally be an advantage as the solution rate is thus increased. The hydrated lime is often used in the water treatment sector by smaller users that cannot justify the investment for a slaker and the expense of another processing step required when using quicklime.

The limestone products contribute significantly to the sales of the Joliette lime plant. Except for the pulverized limestone (minus 150 μm) which is mainly used as a filler material in the manufacture of roof shingles, the other products, aggregate stone and agricultural stone, are very seasonal. Nevertheless, the sales of aggregate stone can exceed 500,000 tonnes.

3. PROCESS DESCRIPTION

3.1 Lime Process Flow

A general process flow sheet for lime manufacture is illustrated in Figure I. Lime manufacture can be simplified to three basic steps:

- stone preparation (kiln feed),

- calcination,

- lime hydration.

The stone preparation comprises selective mining, primary crushing, stone classification by screening, and secondary crushing of the oversize (plus 50 mm) in closed circuit with screening.

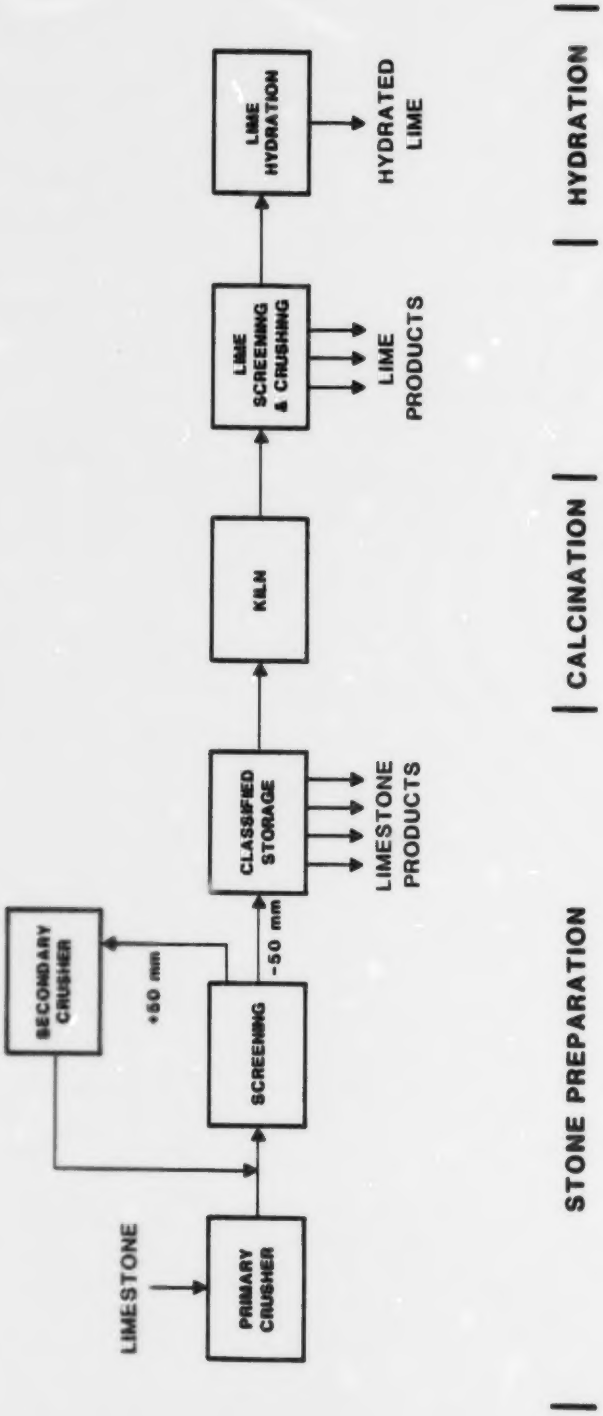
The kiln feed is made up by reclaiming given proportions of different sizes of limestone from the classified storage. The stone gradation determines the size distribution of the quicklime obtained after calcination. After cooling, quicklime may be stored as such, classified by screening or crushed. This further processing will be according to customers' specifications. Quicklime is shipped directly to customers in bulk containers by train or truck.

Production of hydrated lime involves supplementary processing steps:

- crushing,
- mixing quicklime and water,
- removal of impurities and uncalcined cores by air classification.

Figure I - LIME PROCESS FLOW SHEET

DOMTAR JOLIETTE PLANT



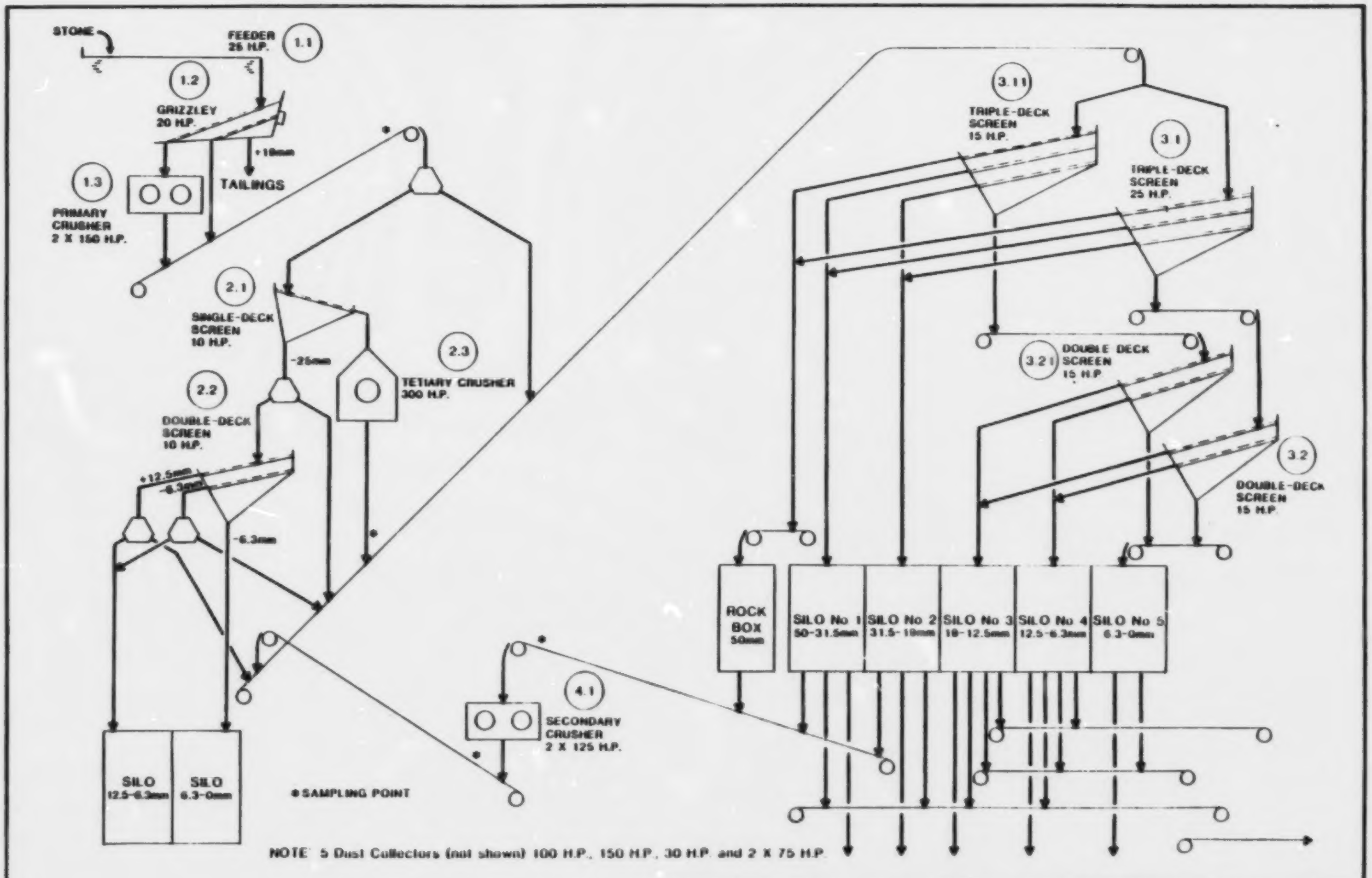
3.2 Limestone Crushing and Classification

The limestone processing at the Joliette plant is illustrated by the flow diagram in Figure II. The equipment that was monitored during the study is listed in Table 3.

The limestone crushing and screening circuit is capable of producing lime-type stone at a rate of over 500 t/h. This throughput, in fact, is dependent on the truck fleet transporting rocks from the quarry (four trucks were in use during the period of observation). Impact crushers are used for size reduction as their angular products are preferred by the aggregate industry.

Primary crushing is an open circuit composed of a reciprocating feeder, a vibrating double-decker grizzly and a Cedarapids double impeller impact breaker, Model 4350H. The impact breaker is powered by two 150 HP motors. The large dust collecting capacity is powered by a 100 HP motor.

When producing aggregates or construction stone where larger quantities of the smaller fractions are desirable, the stone flow passes the equipment numbered 2.1 to 2.4 on the sketch. The equipment used for these products comprises a set of two screens and another crusher used to reduce the oversize. During the observations this equipment was not operational, except for the dust collector powered by a 75 HP motor.



NOTE: 5 Dust Collectors (not shown) 100 H.P., 150 H.P., 30 H.P. and 2 X 75 H.P.

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FIGURE II
LIMESTONE CRUSHING & SCREENING
FLOW DIAGRAM

PRODUITS CHIMIQUES
DOMTAR - JOLIETTE, P.Q

PROJECT No. 20010

TABLE 3 - LIMESTONE CRUSHING AND SCREENING PLANT
- EQUIPMENT LIST (COMMINUTION ONLY)

	EQUIPMENT	MOTOR	
No.	TYPE/MAKE/MODEL	HP	AMPS
1.1	RECIPROCATING FEEDER	25	24
1.2	VIBRATING GRIZZLY	20	20
1.3	PRIMARY CRUSHER: DOUBLE IMPELLER IMPACT BREAKER - CEDARAPIDS, MODEL 4350H	150 150	150 150
1.4	DUST COLLECTOR - 25,000 CFM	100	100
2.1	VIBRATING SCREEN - SINGLE DECK -5' X 10' HEWITT-ROBINS M-11	10	10
2.2	VIBRATING SCREEN - DOUBLE DECK - 5' X 16' HEWITT-ROBINS M-11	10	10
2.3	TERTIARY CRUSHER - PULVOMATIC IMPACTOR - 4000 volts	300	40
2.4	DUST COLLECTOR - 15,000 CFM	75	75
3.1	VIBRATING SCREEN - TRIPLE DECK - 5' X 16' HEWITT-ROBINS	25	25
3.11	VIBRATING SCREEN - TRIPLE DECK - 5' X 16' HEWITT-ROBINS	15	16
3.2	VIBRATING SCREEN - DOUBLE DECK - 5' X 16' HEWITT-ROBINS	15	16
3.21	VIBRATING SCREEN - DOUBLE DECK - 5' X 16' HEWITT-ROBINS	15	16
3.3	DUST COLLECTOR (SCREENING PLANT) 30,000 CFM	150	150
3.4	DUST COLLECTOR (CONVEYORS) - 5,000 CFM	30	30
4.1	SECONDARY CRUSHER: DOUBLE IMPELLER IMPACT BREAKER - CEDARAPIDS, MODEL 3645	125 125	125 125
4.2	DUST COLLECTOR - 15,000 CFM	75	75

Note: All motors are 550 volts, except where noted.

For lime production, the crushed stone is transferred to the main screening plant (equipment numbers starting with a 3 in the diagram) where the stone is classified into five size fractions and stored in 180 tonne silos. The stone classification is effected by dividing the flow between two sets of two screens, the first being a triple deck and the second a double deck. The oversize fraction (plus 50 mm) is fed to a Cedarapids double impeller impact breaker, Model 3645, powered by two 125 HP motors, which serves as a secondary crusher placed in closed circuit with the screening plant. The dust collector fan motors are large with a total installed power of 255 HP.

3.3 Lime Crushing and Screening

The essential steps of lime processing are illustrated in the flow diagram of Figure III. This diagram is a simplification of the actual handling system. Most equipment is duplicated, except for the rolls crusher and the hammermill. Lime can be either stored, screened or crushed before being put in a loadout silo. It can also be directed to the steelworks lime screening or the hydrate plant.

The equipment monitored in the lime handling department is listed in Table 4.

The equipment consists of two double-deck vibrating screens, one 40 HP Pioneer double roll crusher and one 40 HP Jeffrey hammermill. To be noted again is the importance of the power installed for dust collection.

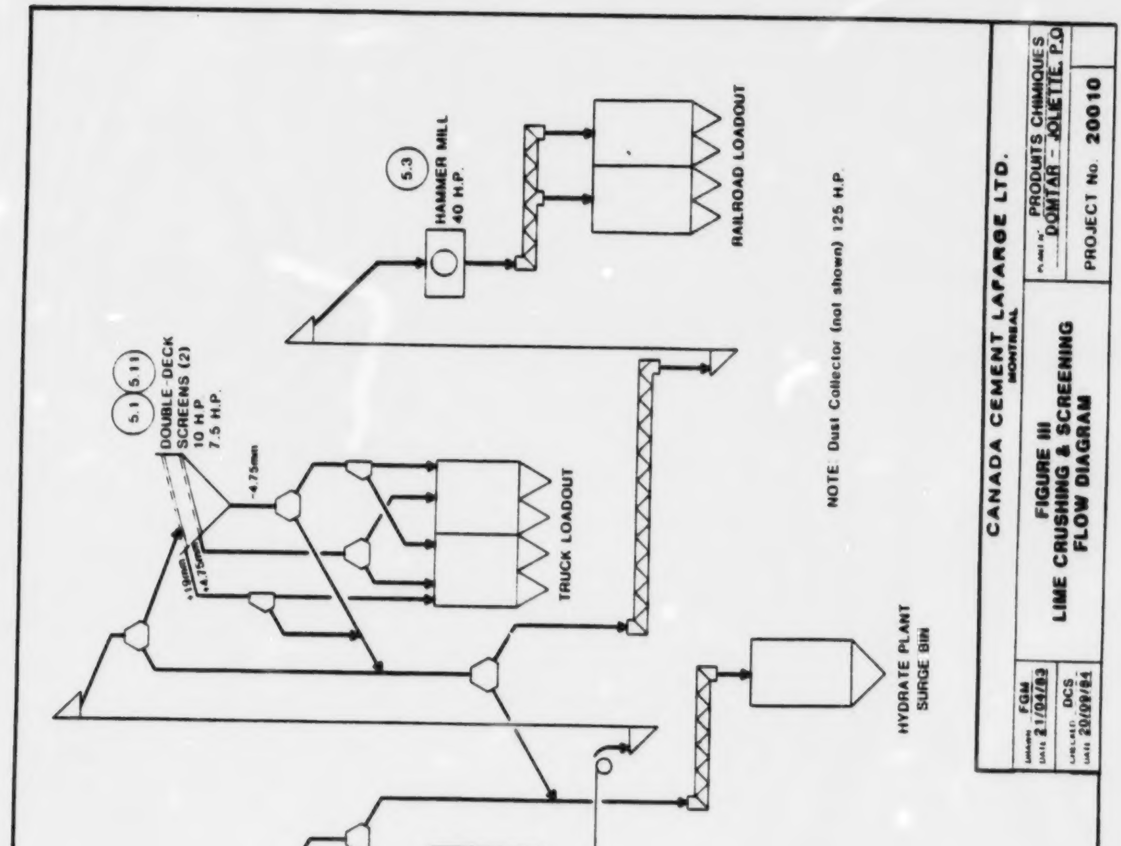

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FIGURE III
LIME CRUSHING & SCREENING
FLOW DIAGRAM

PRODUITS CHIMIQUES
DOMTAR - JOLIETTE, P.Q

PROJECT No. 20010

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TABLE 4 - Lime Crushing and Screening

	EQUIPMENT	MOTOR	
No.	TYPE/MAKE/MODEL	HP	AMPS
5.1	VIBRATING SCREEN - DOUBLE DECK - 4' x 10' C-E TYLER TY-ROCK	10	10
5.11	VIBRATING SCREEN - DOUBLE DECK - 4' x 10' C-E TYLER TY-ROCK	7.5	8
5.2	DOUBLE ROLL CRUSHER - PIONEER	40	40
5.3	HAMMERMILL - JEFFREY 2420	40	40
5.4	DUST COLLECTOR - 28,000 CFM	125	125

The steel industry specifies a pebble lime with minimal content of fines (minus 6.3 mm). Therefore, this lime is processed separately by applying a screening operation twice to remove the minus 6.3 mm fraction.

The process flow is depicted in the flow diagram of Figure IV. The equipment monitored were only the two double-deck vibrating screens with characteristics listed as follows:

TABLE 5 - Steelworks Lime Screening

	EQUIPMENT	MOTOR	
No.	TYPE/MAKE/MODEL	HP	AMPS
6.1	VIBRATING SCREEN - DOUBLE DECK - 4' x 10' C-E TYLER TY-ROCK	10	10
6.2	VIBRATING SCREEN - DOUBLE DECK - $2m^2$ ROYER/MOGENSEN (ELECTRICALLY VIBRATED)	2 x 3	5.1

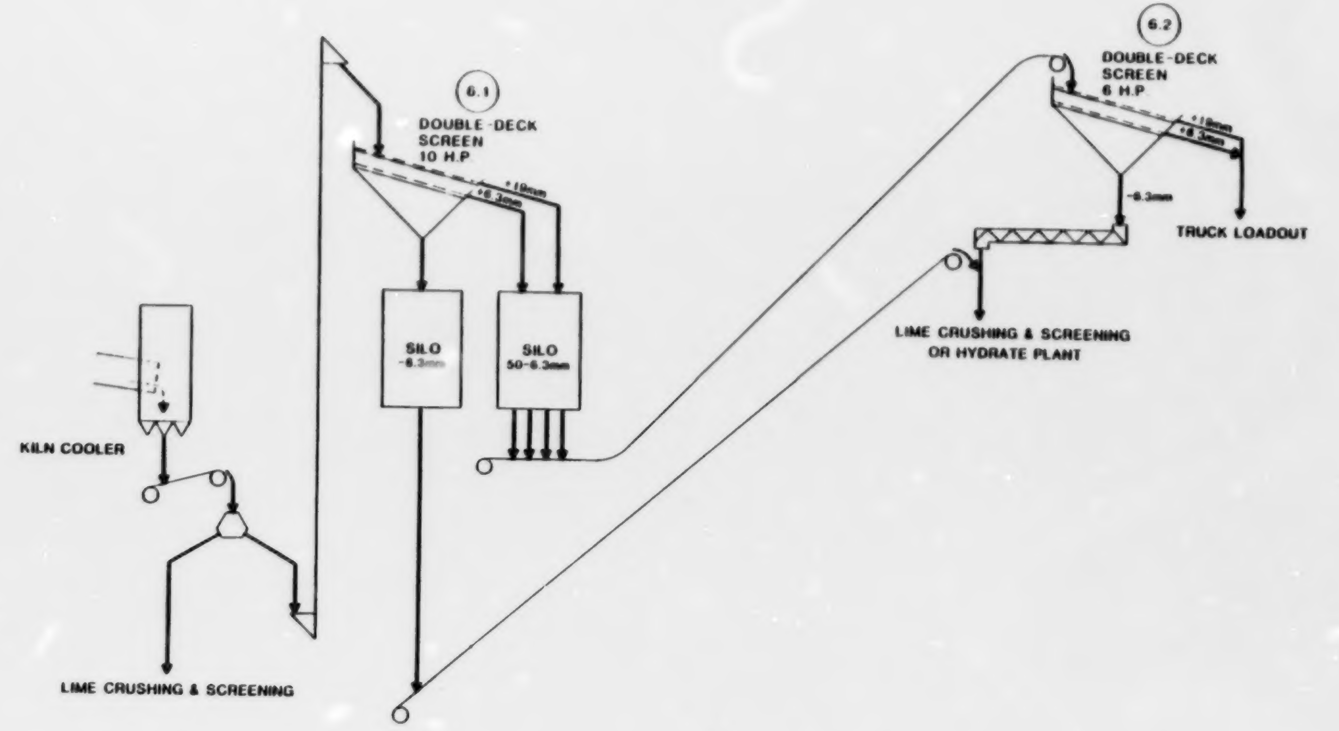

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FIGURE IV
STEELWORKS LIME SCREENING
FLOW DIAGRAM

PLANT N° PRODUITS CHIMIQUES
DOMTAR - JOLIETTE, P.Q.

PROJECT No. 20010

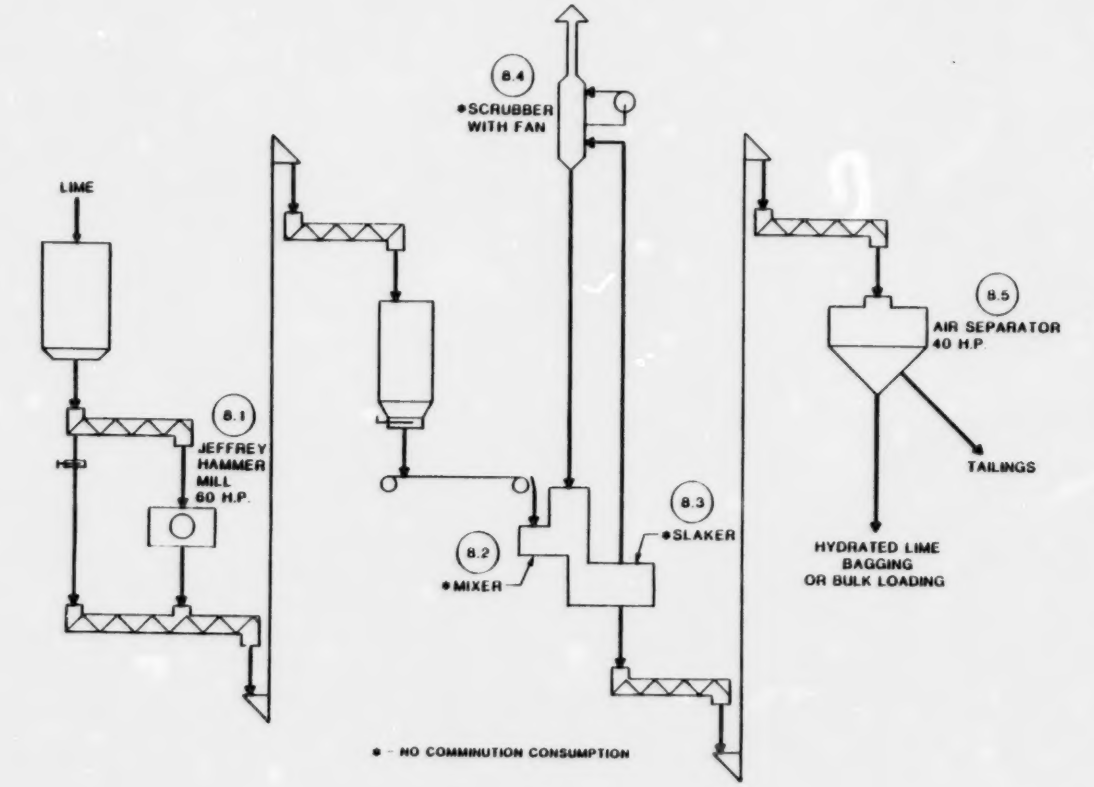
3.4 Hydrated Lime Plant

A simplified process flow is shown in the flow diagram of Figure V. To shorten the reaction time, lime is crushed in a 60 HP Jeffrey hammermill before being fed to the mixer. For the hydration of lime, sufficient water must be added for the hydration reaction. Well-proportioned quantities of lime and water are introduced to a mixing chamber (8.2) where a slurry is formed before being transferred to the hydrator proper (8.3) in which the chemical reaction takes place. This reaction is highly exothermic and generates large amounts of steam and dust that are recuperated and returned to the mixer by a scrubber (8.4) using a specially designed fan-washer.

Once hydrated, an air separator is used to remove coarse particles of impurities and unhydrated lime. Only the hammermill and separator were monitored.

TABLE 6 - Hydrated Lime Plant

	EQUIPMENT	MOTOR	
No.	TYPE/MAKE/MODEL	HP	AMPS
8.1	HAMMERMILL - JEFFREY 2430	60	60
8.2	MIXER	-	-
8.3	LIME HYDRATOR	-	-
8.4	SCRUBBER WITH FAN	-	-
8.5	AIR SEPARATOR - 14' GAYCO	40	38



* - NO COMMINUTION CONSUMPTION

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FIGURE V
HYDRATED LIME PLANT
FLOW DIAGRAM

PLANT PRODUITS CHIMIQUES
DOMTAR - JOLIETTE, P.Q

PROJECT No 20010

4. RESULTS AND DISCUSSION

The results of the data collection campaign are grouped under the following main headings, limestone crushing and screening, and lime crushing and screening.

4.1 Limestone Crushing and Screening

4.11 Electrical Measurements

A summary of the electrical measurements obtained on the limestone crushing and screening circuit is presented in Table 7.

TABLE 7 - Limestone Crushing and Screening

No.	EQUIPMENT	MOTOR HP	POWER OBSERVATIONS - kW		
			MAX.	MIN.	AVG.
1.1	FEEDER	25	8	1	2
1.2	GRIZZLY	20	8	8	8
1.3	PRIM. CRUSHER	150	138	6	90
		150	270	12	122
1.4	DUST COLLECTOR	100	51	51	51
2.4	TERT. CRUSHER DUST COLLECTOR	75	52	52	52
3.1	TRIPLE-DECK SCREEN	25	8.9	8.9	8.9
3.11	TRIPLE-DECK SCREEN	15	6.7	6.7	6.7
3.2	DOUBLE-DECK SCREEN	15	4.5	4.5	4.5
3.21	DOUBLE-DECK SCREEN	15	4.5	4.5	4.5
3.3	DUST COLLECTOR (SCREENS)	150	32	32	32
3.4	DUST COLLECTOR (CONVEYORS)	30	11.4	11.4	11.4
4.1	SEC. CRUSHER	125	44	12	28
		125	18	18	18
4.2	DUST COLLECTOR	75	26	26	26

The power level observations for the crushers, the feeder and the grizzly screen were obtained during a sufficiently long period of power level recording for the respective equipment. Typical examples are available in the working papers.

The following table summarizes the electrical measurements in terms of crusher motor loading. The primary crusher is well loaded while the secondary crusher works lightly.

TABLE 8 - Crusher Motor Load

CRUSHER	% NOMINAL POWER
Primary	94.7
Secondary	24.7

The power demand for dust collectors is large and totals 172 kW.

4.12 Flowrates

The flowrates of the limestone crushing and screening circuit have been determined by using the quarry truck-load count.

Three days of operation were used. The count of trucks during a day is multiplied by the average truckload weight (established by weighing randomly 6 to 9 trucks during the day) to give the overall day production. The total production for each of the three days, based on 8-hour shifts, was as listed below.

DATE	PRODUCTION (tonnes)
April 4	2507
April 6	3384
April 7	2706

The hours of actual operation during this period of three 8-hour shifts totalled 17.45 hours and the average production rate is thus calculated at 492.6 t/h. The actual production rate, when the primary crusher is continuously fed, is estimated at 680 t/h. This does not take into account any stoppage and could be called the potential flowrate. Such a potential flowrate cannot be directly translated in capacity without assuming a reasonable value for the utilization factor. By using this potential production rate the average production rate observed during three days represents an utilization factor of over 72%. These results are summarized in the following table.

PRIMARY CRUSHER FLOWRATE	
POTENTIAL FLOWRATE, t/h	680
AVERAGE FLOWRATE, t/h	493
UTILIZATION FACTOR, %	72.4

The flowrate through the secondary crusher was determined by taking two simultaneous belt-cut samples before and after this crusher. A 1.83 m cut weighing 51.43 kg was taken on belt #6 and a 1.63 m cut weighing 41.45 kg, on belt #7. Using the measured belt speeds which were respectively 127.1 m/min for belt #6 and 137.2 m/min for belt #7, the following flowrates were determined:

SECONDARY CRUSHER FLOWRATE	
BELT #6 SAMPLING, t/h	214.5
BELT #7 SAMPLING, t/h	209.8

The secondary crusher capacity is estimated at 210 t/h.

The average flowrate of the secondary crusher is estimated a 152 t/h and is obtained by multiplying the flowrate at full production by the circuit utilization factor.

4.13 Size Distribution

A typical product size distribution for the crushing circuit product is given in the following table:

CIRCUIT PRODUCT SIZE DISTRIBUTION	
mm	% passing
50.0	100
31.5	86
19.0	64
12.5	41
6.3	20

The size range of the primary crusher feed was minus 1250 mm, plus 150 mm and mainly minus 600 mm, plus 300 mm.

The primary crusher product was not sampled but its size distribution can be estimated through an approximate material balance of the circuit. For this purpose, the evaluation of the secondary crusher flowrate as well as its feed and product size distributions have been used. This has led to the following estimated size distribution.

PRIMARY CRUSHER PRODUCT SIZE DISTRIBUTION	
mm	% passing
150	100
100	94
50	72
25	45
12.5	25
6.3	12

The secondary crusher feed and product size distributions were both sampled and the following table presents a summary of the feed and product size distributions.

SECONDARY CRUSHER FEED AND PRODUCT SIZE DISTRIBUTIONS		
mm	% feed passing	% product passing
132.5	100	
100	80	
75	60	100
50	13	87
38.1	3	79
25		58
19		46
12.5		31
9.5		24

More detailed results are available in working papers.

4.14 Grindability Testing

The grindability tests on the limestone by both the Hardgrove and Bond test procedures were conducted at the CCL Belleville laboratory.

The Hardgrove Index (HGI) is 83. The Bond Index was determined to be 8.86 kWh/Ton.

A typical HGI value for limestone would be in the range of 50-70 which gives an average computed Bond Index of 10.48 kWh/Ton.

4.15 Specific Energy Consumption

The procedure usually used to calculate the specific energy consumption consists in adding up the average power demand of each motor and dividing this total power demand by the average production rate. But, in the case of a crushing operation fed irregularly by truckloads, some caution is required in using the average power demand of a crusher motor as observed on power charts. The average power demand observed is not a true representation of power consumed during a full hour of production: this is due to idle running when no feed is supplied to the primary crusher. The observed power demand must therefore be adjusted down to take into account the non-productive time: the utilization factor previously discussed in 4.12 is used to this effect. Another equivalent approach would be to use the potential flowrate (also discussed in 4.12) as the true instantaneous production rate. This adjustment concerns only the primary crusher.

Accordingly, the average power demand of the primary crusher totalling 212 kW when fully loaded is adjusted by the utilization factor of 0.724 to 153.5 kW. This value is then added to the secondary crusher power demand (46 kW) and the total divided by the average production rate (492.6 t/h) to give a figure of 0.405 kWh/tonne for crushing only.

To this figure must be added the specific consumption of all other motors (auxiliaries) obtained by dividing the total non-crushing average power demand by the average production rate. This amounts to 0.420 kWh/tonne. Then the total circuit specific consumption is the sum of these two figures and totals 0.825 kWh/tonne.

Table 9 summarizes the data developed above and Table 10 gives a distribution of the power consumption between crushing, screening and dust collecting.

TABLE 9 - Limestone Crushing and Screening Specific Power Consumption

	kWh/tonne	%
Crushing Only	0.405	49.1
Auxiliaries	0.420	50.9
Total	0.825	100.0

TABLE 10 - Limestone Crushing and Screening Distribution of Consumption

	%
Crushing Only	49
Screening	9
Dust Collecting	42

The consumption for crushing alone is found to be very low and it must be viewed in relation with the coarse product size (minus 50 mm). On the other hand, auxiliaries and particularly dust collecting account for about half of total consumption. This high proportion can be reduced by increasing the utilization factor at the primary crusher so that the crusher motors are not idling while auxiliary motors are running at constant load. But the reduction in specific consumption would be slight. The alternative would be to examine the potential for reducing the power demand of dust collectors, at least when the primary crusher is idling.

4.2 Lime Processing

4.21 Electrical Measurements

A summary of the electrical measurements obtained on the lime crushing and screening operations is presented in Table 11. These power level observations were estimated for the most part by using the measured amperage and assuming a power factor value. Only two of the crushers were monitored with the recording wattmeter.

TABLE 11 - Lime Processing

No.	EQUIPMENT	MOTOR HP	POWER OBSERVATIONS - kW		
			MAX.	MIN	AVG.
5.1	DOUBLE-DECK SCREEN	10	3	3	3
5.11	DOUBLE-DECK SCREEN	7.5	4	4	4
5.2	ROLL CRUSHER	40	5	5	5
5.3	HAMMERMILL	40	7	7	7
5.4	DUST COLLECTOR	125	70	70	70
6.1	DOUBLE-DECK SCREEN	10	3	3	3
6.2	DOUBLE-DECK SCREEN	6	4	4	4
8.1	HAMMERMILL	60	14	14	14
8.5	AIR SEPARATOR	40	16	16	16

The measurements show the low level of power consumption, particularly on the crushers which are run by sizeable motors. The hammermills use a flywheel to stabilize the mechanical load and as a consequence have a high starting power demand. Another observation is the high power load involved in dust collecting (No. 5.4) which results from the extensive and sophisticated lime handling system serving the lime discharge of three kilns. But it would be unfair to attribute to the lime crushing and screening operation the whole power demand of the dust collector; only a fraction of this demand would be needed for the air volume handled for both the roll crusher and hammermill. As this air volume is estimated at 5780 m^3/h and represents about 12% of the dust collector nominal capacity of 47570 m^3/h, only this fraction of the observed 70 kW (or 8.5 kW) will be used in calculating the specific consumption. Finally, the screens are shown to represent very small electrical loads.

4.22 Flowrates

There are basically three lime processing routes: the crushing and screening of minus 4.75 mm (-3/16") lime, the screening of steelworks lime and the preparation of lime for hydration.

The flowrates needed to compute specific power consumptions are listed in Table 12. They are based on plant records and were not actually measured.

TABLE 12 - Lime Flowrates

PROCESS UNIT	t/h
Raw Lime Screening (5.1)	14.5
3/16 Inch Lime Crushing (5.3)	8.5
Steelworks Lime - 1st Screening (6.1)	16.8
Steelworks Lime - 2nd Screening (6.2)	136
Hydrate Plant (8.1 & 8.5)	14.5

4.23 Size Distribution

Two crushing operations are involved: the production of minus 4.75 mm lime and the preparation for the production of hydrated lime.

In the production of minus 4.75 mm lime, the feed of the crusher consists of a plus 19 mm fraction accounting for one third of the feed and a minus 4.75 mm fraction accounting for two thirds. This feed results from the screening of raw lime whereby the mid-fraction is extracted and sold as a product.

The crushed product obtained has the following size distribution:

3/16 INCH LIME SIZE DISTRIBUTION	
mm	% passing
6.70	100
4.75	95
2.36	80
1.18	65
0.60	45

For lime used for hydration, the feed of the crusher can be a raw kiln product, a screened fraction or fines recuperated from dust collection. The fineness of the crushed lime is minus 2.36 mm.

4.24 Grindability Testing

Grindability tests on lime by both the Hardgrove and Bond test procedures were conducted. The test results, as expected, show it to be extremely easy to grind. The Hardgrove Index (HGI) was determined to be 165. The Bond test gave a value of 4.2 kWh/Ton.

4.25 Specific Energy Consumption

Table 13 gives the specific power consumption obtained for lime crushing and screening depending on the lime produced. The specific consumption of the 3/16 inch lime takes into account raw lime screening and dust collection, the latter established on an 8.5 kW demand. In the case of hydrated lime, the auxiliary equipment is the air separator.

TABLE 13 - Lime Processing
Specific Power Consumption

	3/16" Lime		Steelworks Lime		Hydrated Lime	
	kWh/t	%	kWh/t	%	kWh/t	%
Crushing	0.82	36.0	-	-	0.97	47.5
Auxiliaries	1.46	64.0	0.20	100	1.07	52.5
Total	2.28	100	0.20	100	2.04	-

These data show lime crushing and screening power consumption to be rather low. As for limestone crushing, auxiliaries account for about half of total consumption. It is striking to note that the lime crushing specific consumption is roughly double that of limestone crushing. This would suggest that the crushers are probably underfed.

The overall lime product power consumption, including limestone crushing, is given in Table 14.

TABLE 14 - Lime Products Power Consumption
Cumulative Specific Consumption

	3/16" Lime		Steelworks Lime		Hydrated Lime	
	kWh/t	%	kWh/t	%	kWh/t	%
Crushing	1.60	41.3	0.78	43.6	1.74	47.9
Auxiliaries	2.27	58.7	1.01	56.4	1.89	52.1
Total	3.87	100.0	1.79	100.0	3.63	100.0

These calculations take into account the yield factor of the calcining process, i.e. one tonne of limestone yields 0.52 tonne of quicklime and conversely 1.92 tonne of limestone is used to obtain one tonne of lime product.

The power consumption for total comminution, including auxiliaries, in the lime industry is low at just under 4 kWh/tonne. Moreover, a large part of lime production does not require crushing but only screening to remove fines (steelworks lime).

From company records, total consumption was estimated to average 31 kWh/tonne of product. Assuming 3 kWh/tonne, comminution including auxiliaries would represent about 10% of the total electric energy consumption.

In summary, there is no great potential for electrical energy savings in the lime industry.

The study has brought out the importance of the power consumption attributable to air pollution control. This was established clearly in limestone crushing and screening where dust collection accounts for 42% of total power consumption.

Savings would be had by reducing air flows through dust collectors when crushers are idling. A system can be engineered that would automatically close down dampers during idle periods. This would reduce power demand on fan motors for an appreciable amount of time.

APPENDIX

INDUSTRY REVIEW

GENERAL INFORMATION

The Mineral and Its Processing

Lime is a term that should actually be used only to identify calcined limestone. This is also known as quicklime or calcium oxide (CaO). A secondary product of quicklime is hydrated lime or slaked lime ($Ca(OH)_2$).

Basically, there are two types of limestone: high calcium ($CaCO_3$) and high magnesium (dolomitic) ($CaCO_3.MgCO_3$) limestones. High calcium quicklime contains usually 0.5 to 2.5% magnesium oxide while dolomitic quicklime contains 35 to 40% magnesium oxide.[1]

Most quicklimes (CaO) correspond in size to the original crushed rock which varies from 25 to 200 mm and as such is called lump lime. Crushed or pebble lime is a product ranging in size from 6 to over 60 mm. Screened quicklime fines are sometimes compressed (pelletized) into one-inch pellets. For some purposes, ground or pulverized forms of quicklime are used, ranging from 2 mm to dust.[1]

Since quicklime has great affinity for moisture and carbon dioxide, it is perishable. As a chemical material it is desirable to reduce atmospheric exposure during handling and storage to a minimum. Lime is usually consumed within a few weeks of manufacture.[2]

Hydrated lime is more stable. It is obtained by adding water to quicklime hydrating it into a dry, fine, subsieve size white powder. Because its affinity for moisture has been satisfied, it is not as vulnerable to moisture as quicklime. However, it has the same strong affinity for carbon dioxide.[2]

Lime's extensive use in industry has made it second to sulfuric acid in tonnage among basic chemicals. However, in the early 1900's it was regarded primarily as a building material for mortar and plaster; over 80% was used in building construction. But today, the chemical and industrial uses account for more than 90% of lime consumption, with building construction uses comprising only 8% - a complete end-use reversal.[2]

Production of lime involves three main processes: stone preparation, calcination and hydration. The principal carbonate rocks used by industry are limestone and dolomite. Limestones are sedimentary rocks composed mostly of calcite ($CaCO_3$) and dolomites are sedimentary rocks composed mostly of dolomite ($CaCO_3.MgCO_3$). High-purity limestone and dolomite represent the raw materials of the lime industry. Because lime must meet exacting chemical specifications, the various steps in stone production are carefully controlled to prevent contamination with undesirable impurities, particularly silica, alumina, and iron oxide.[2]

"Quicklime (CaO or CaO.MgO) is formed by calcination in which limestones are heated to the dissociation temperature of the carbonates (as low as 402°C for $MgCO_3$ and as high as 898°C for $CaCO_3$) and held at that temperature over sufficient time to release carbon dioxide. Secondary products are slaked lime and hydrated lime. Slaked lime is the product of mixing quicklime and water; hydrated lime is slaked lime dried and possibly reground."[3]

Canadian Industry[3]

"Lime is a high-bulk and comparatively low-cost commodity. It is uncommon to ship it long distances because the raw material for its manufacture is available in many localities. The preferred location for a lime plant is near the principal lime markets, adjacent to a source of high-quality raw material and close to a supply of energy."[3]

The more heavily populated and industrialized provinces of Ontario and Quebec together produced over 80 percent of Canada's total lime output in 1980, with Ontario contributing about two-thirds of Canada's total.

Recent lime production statistics are given in Table 1 below. The distribution by province is also given in this table.

TABLE 1 - Canada, Lime Production and Trade, 1980 and 1982[3]

	1981		1982P	
	(tonnes)	($000)	(tonnes)	($000)
PRODUCTION[1]				
By Type				
Quicklime	2 359 000	142,070	2 010 000	..
Hydrated Lime	196 000	11,804	181 000	..
Total	2 555 000	153,874	2 191 000	148 861
By Province				
Ontario	1 773 000	106,815	1 463 000	99,484
Quebec	365 000	21,956	329 000	22,444
Alberta	183 000	11,047	159 000	10,812
British Columbia	111 000	6,671	107 000	7,077
Manitoba	..	4,450	..	5,100
New Brunswick	..	2,935	..	3,944
Total	2 555 000	153,874	2 191 000	148,861

Sources: Energy, Mines and Resources Canada; Statistics Canada.
[1] Producers' shipments and quantities used by producers.
P Preliminary; - Nil; .. Not available.

Production figures do not include some captive production such as that from pulp and paper plants that burn sludge to recover lime for reuse. With the addition of some new and larger capacity in recent years the industry could produce about 3.5 million tonnes per year.

The evolution of lime production, trade and apparent consumption during the last decade can be seen from Table 2. The apparent consumption has increased steadily but at a slow rate. Exports have more than doubled during this period.

TABLE 2 - Canada Lime Production, Trade and Apparent Consumption, 1970, 1975-82[3]

(tonnes)

Year	Quick	Hydrated	Total[1]	Imports	Exports	Consumption[2]
1970	1 296 590	224 026	1 520 616	30 649	181 994	1 369 271
1975	1 533 944	199 195	1 733 139	30 099	234 034	1 529 204
1976	1 703 374	227 019	1 930 393	36 282	309 355	1 657 920
1977	1 767 406	232 638	2 000 044	24 480	359 540	1 664 984
1978	1 857 580	176 631	2 034 211	31 130	478 552	1 586 789
1979	1 662 405	196 920	1 859 325	41 480	490 863	1 409 942
1980	2 364 000	190 000	2 554 000	40 901	403 166	2 191 735
1981	2 269 000	194 000	2 463 000	23 046	431 002	2 055 044
1982[P]	2 010 000	181 000	2 191 000	15 963	281 137	1 925 826

Sources: Energy, Mines and Resources Canada; Statistics Canada.

[1] Producers' shipments and quantities used by producers.

[2] Production, plus imports, less exports.

[P] Preliminary.

The Canadian lime producing companies are listed in Table 3. Those producing for a captive use are indicated. They concern mainly sugar beet processing and metal producing companies.

It is also noteworthy that three companies, Domtar Inc., Steetley Industries Ltd., and Steel Brothers Canada Ltd. have operated, in recent years, production facilities in the United States.

TABLE 3 - Canadian Lime Industry, 1982[3]

PROVINCE & COMPANY	PLANT LOCATION	TYPE OF QUICKLIME
New Brunswick		
Havelock Processing Ltd.	Havelock	High-calcium[2]
Quebec		
Domlim Inc.	Lime Ridge	High-calcium[2]
	St. Adolphe de Dudswell	High-calcium
Domtar Inc.	Joliette	High-calcium[2]
Gulf Canada Ltd., Shawinigan Chemical Division	Shawinigan	High-calcium[2]
Quebec Sugar Refinery[1]	St. Hilaire	High-calcium
Ontario		
The Algoma Steel Corp. Ltd.[1]	Sault Ste Marie	High-calcium & dolomitic
Allied Chemical Canada, Ltd.[1]	Amherstburg	High-calcium
BeachviLime Limited	Beachville	High-calcium
Guelph DoLime Limited	Guelph	Dolomitic[2]
Chromasco Limited[1]	Haley	Dolomitic
Domtar Inc.	Beachville	High-calcium[2]
Reiss Lime Co. of Canada Ltd.	Spragge	High-calcium
Stelco Inc.	Ingersoll	High-calcium
Steetley Industries Limited	Dundas	Dolomitic
Manitoba		
The Manitoba Sugar Co. Ltd.[1]	Fort Garry	High-calcium
Steel Brothers Canada Ltd.	Faulkner	High-calcium
Alberta		
Canadian Sugar Factory Ltd.[1]	Taber	High-calcium
	Picture Butte	High-calcium
Steel Brothers Canada Ltd.	Kananaskis	High-calcium[2]
Summit Lime Works Limited	Hazell	High-calcium & dolomitic[2]
British Columbia		
Steel Brothers Canada Ltd.	Kamloops	High-calcium
Texada Lime Ltd.	Fort Langley	High-calcium

Source: Energy, Mines and Resources Canada.

[1] Production for captive use.

[2] Hydrated lime produced also.

Market Outlook

Lime is used principally in the steel, pulp and paper, and mining industries where its chemical qualities are required as a flux, in digesting liquors and as a neutralizing agent, respectively. A typical distribution by use is given in Table 4.

TABLE 4 - Canada, Consumption of Lime, Quick and Hydrated, 1980 and 1981 (Producers' Shipments and Quantities Used by Producers, By Use)[3]

	1980		1981P	
	(tonnes)	($000)	(tonnes)	($000)
Chemical and Metallurgical				
Iron & steel plants	1 169 281[2]	59,166	1 237 519[2]	74,529
Pulp & paper mills	303 484	15,356	271 945	16,378
Water & sewage treatment	113 219	5,729	22 760[3]	1,371
Nonferrous smelters	113 818[2]	5,759	117 632[2]	7,085
Cyanide & flotation mills	68 805[2]	3,481	(4)	(4)
Sugar refineries	19 006	962	25 841	1,556
Other industrial[1]	643 531	32,563	690 040	41,557
Agricultural	17 084[3]	864	17 370	1,046
Road stabilization	8 716[3]	441	9 338[3]	565
Other uses	97 056	4,911	162 555	9,787
Total	2 554 000	129,232	2 555 000	153,874

Sources: Statistics Canada; Energy, Mines and Resources Canada.

[1] Includes glassworks, fertilizer plants, tanneries, uranium plants and other miscellaneous industrial uses.

[2] Figures represent quicklime only. Figures for hydrated lime are included in "other industrial" to avoid disclosing confidential company information.

[3] Figures represent hydrated lime only. Figures for quicklime are included in "other uses".

[4] Confidential figures are included in "other industrial works".

P Preliminary.

The largest single market for lime is provided by the metallurgical industry, particularly by the steel industry which has afforded during the past decade the largest increase in lime consumption. With increased application of the basic oxygen furnace (BOF) and of the electric arc furnace, lime consumption has increased greatly in certain areas of the United States and Canada. The pulp and paper industry is currently the second-largest consumer of lime, most of which is used in the preparation of digesting liquor and in pulp bleaching.

Lime is also used in many sectors of the mining and metal processing industry serving in various ways for the beneficiation of ores, the extraction of metals or as a neutralizing agent. There are many other uses of lime as a chemical or as a raw material but they cannot all be described in this study.

Future expansion is foreseen in the field of environmental pollution control, particularly in the treatment of water supplies and sewage or in the removal of sulphur dioxide from stack gases.

Chemical lime designates a type of quick or hydrated lime low in impurities and possessing a high degree of reactivity making it suitable for use in chemical processes. In industry the value of lime for most purposes is dependent on its content of available lime (CaO). The purity of lime is influenced primarily by the quality of the limestone and secondly, by its method of manufacture. The majority of limestones used for lime manufacture averages around 98 percent total carbonates. The chief impurities are silica, alumina and other metal oxides, in particular iron and manganese oxides. These impurities react with some of the calcium oxide in the kiln producing mineral forms (silicates, aluminates, etc) that are unavailable for chemical uses. Consequently, the purest quicklimes have available lime contents of 94-96 percent. Typical analyses of commercial limes are shown in the following table.[2]

TABLE 5 - Typical Analyses of Commercial Quick Limes

Component	High Calcium Quicklimes Range* %	Dolomitic Quicklimes Range* %
CaO	93.25 - 98.00	55.50 - 57.50
MgO	0.30 - 2.50	37.60 - 40.80
SiO_2	0.20 - 1.50	0.10 - 1.50
Fe_2O_3	0.10 - 0.40	0.05 - 0.40
Al_2O_3	0.10 - 0.50	0.05 - 0.50
H_2O	0.10 - 0.90	0.10 - 0.90
CO_2	0.40 - 1.50	0.40 - 1.50

Source: Chemical Lime Facts, National Lime Association[1]

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* The values given in this range do not necessarily represent minima and maxima.

Hydrated limes are produced in a purer form than quicklime, since in the milling of the dry hydrate air separation devices are used which remove most of the coarse particles - namely "core" (unburned carbonates), silicates and aluminates. As a result, hydrates of 72 to 74 percent available lime are produced with chemically combined water content of 23 to 24 percent.[2]

The other impurities in limestone are trace elements which are monitored according to the end-use of lime and to customer's specification. These are sulfur, phosphorus, arsenic, manganese, strontium and fluorine.

Quicklime is commercially available in bulk or bags, in a number of more or less standard sizes as follows.[1,2,4]

Lump lime	- Usually the product of various vertical kiln processes ranging in size from 90 to 200 mm.
Pebble lime	- Usually the product of rotary kiln ranging in size from 6.3 to 63 mm.
Ground lime	- Typically the size gradation is about 100% passing 2.36 mm and 2-4% passing 150 µm. It is a sized kiln product or the result of grinding and classifying coarser sizes.
Pulverized	- Typical size gradation is about 100% passing 850 µm and 85-95% passing 150 µm. Usually this product is a secondary product and is the direct result of pulverization and classification.

Briquettes (pelletized)	- These are 25 mm sized pellets or briquettes molded from quicklime fines.

Hydrated lime is generally shipped in 25-kilo paper bags,in bulk tank trucks or rail cars. Due to the hydration process hydrated lime is by necessity of fine particle size. Normal grades of hydrate will have 85% or more passing 75 µm, while for special applications air classified hydrated lime may be obtained as fine as 99.5% passing 45 µm.

Most of the product specifications are user-oriented. Within the industry three criteria appear to be the most common. They are: available lime content (calcium oxide), sulphur content and particle size.

The greater the purity of the lime, the more desirable it is for chemical uses. This quality feature depends largely on the purity of limestone, i.e. on minimal impurity content, particularly silica and alumina. A correlated criterion is the chemical reactivity which is dependent on many interrelated factors among which are the burning process, the degree of burning, the grain size of limestone, etc. This property of lime is estimated by measuring the loss on ignition of quicklime. A more reactive lime is a soft-burned lime still containing some residual CO_2. But excessive underburning indicated by a core of uncalcined limestone (over 2% LOI) implies a decrease in the available lime content.

The measurement of Available Lime Index is done by a method called the "Rapid Sugar Test", described in the ASTM specification C25-79 "Standard Methods of Chemical Analysis of Limestone, Quicklime and Hydrated Lime".[4]

For some industrial purposes, sulphur content may be the most important criterion. This is particularly the case in the steel making industry where it is desirable to use a lime with minimal sulphur content. In this most important market, lime is in fact used as a flux to purify steel by removing mainly phosphorus and sulphur. In other industrial uses, sulphur content is not an important criterion.

The particle size of lime is generally an important criterion depending on the end use. Again, the steel industry requires usually a lime in pebble form containing no fines (minus 6.3 mm). Other industries using lime in chemical processes will specify crushed lime or fines so that the rate of solution is increased. Still, other industries prefer to use a narrow distribution of small-size pebble lime, typically a 6.3 to 19.0 mm distribution.

Lime users do not typically care about the size distribution or any criteria of specific surface area measurement. A maximum size limit is usually specified. Size distribution is determined through standard mechanical sieving on sieve sizes established in ASTM E11-70 specification. The lime industry has generally standardized on 45 µm as being the lowest practical sieving limit for reasonable accuracy. The standard dry sieving method is satisfactory for quicklime but unsatisfactory for hydrated lime. With the latter, a wet sieving procedure is strongly recommended.[4]

REFERENCES

THE LIMESTONE INDUSTRY

ENERGY CONSERVATION IN THE INDUSTRIAL
MINERALS PROCESSING SECTOR - COMMINUTION

(Phase I - Plant Studies)

Work on this Project was conducted by
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   2. Product Characteristics
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REFERENCES

1. INTRODUCTION

Cooperating Company:

Domtar Incorporated

Plant Location:

Joliette, Quebec

The report introduces first the company that cooperated in the study. A description follows of the comminution processes monitored during the field work at the company's plant. The measurements made and results obtained are then reported and discussed and conclusions drawn.

The main report is supplemented by a brief description and comminution power requirement of the calcite processing operations of:

Steep Rock Resources Inc.
Perth, Ontario Plant.

For readers who are not familiar with the limestone industry, an appendix entitled "Industry Review" is added. Details concerning data collection and field work, as well as other raw data or measurements, are available in working papers.

2. COMPANY DESCRIPTION

Domtar Inc. was approached as a representative limestone processor whose comminution operations could be monitored to build the data base required in the Phase I of the project. The lime plant located at Joliette, Quebec, was selected to conduct the data generation campaign.

2.1 General

Domtar Inc. is one of the largest industrial groups in Canada operating over 70 manufacturing plants distributed in Canada and the United States of America. The total sales of the company were close to $1.7 billion in 1982.

The large number of activities and products sold by this company are divided among five operating groups which can be listed in decreasing importance as follows:

1 - Pulp and Paper : 50% of sales
2 - Construction Materials : 19% of sales
3 - Box and Packaging : 15% of sales
4 - Chemical Products : 16% of sales
5 - Energy Resources Investments

2.2 The Lime Division

The limestone products are produced by the Lime Division which is one of four divisions forming the Chemical Products Group. Domtar's Lime Division is the largest lime producer in Canada. In 1982, with sales of $29 million, it accounted for more than 20% of total sales in Canada.

The production capacity is distributed over two plants, one in Ontario and one in Quebec.

The plant located at Joliette, Quebec, has a capacity of 300,000 tonnes per year and produces quick lime and hydrated lime as well as a variety of limestone products for construction and agricultural uses.

2.3 Products Marketed

Typical specifications for Domtar's limestone products are listed in Table 1.

Except for the pulverized limestone (minus 150 µm), mainly used as a filler material in the manufacture of roof shingles, the other products, aggregate stone and agricultural stone, are very seasonal. Nevertheless, the sales of aggregate stone can exceed 500,000 tonnes per year. Pulverized limestone used as filler material can reach 60,000 to 70,000 tonnes per year while agricultural and chemical limestone are each about 25,000 tonnes a year. Pulverized stone is marketed under the name of "Stalco" and agricultural stone under that of "Solpier".

TABLE 1 - Domtar - Joliette Lime Plant
Products Marketed
Limestone Products

1) Aggregate Stone

% Passing	31.5 x 50.0 mm	19.0 x 31.5 mm	12.5 x 19.0 mm	6.3 x 12.5 mm
50.0 mm	100			
38.1	61	100		
25.0	3	68	100	
19.0	1	14	86	100
12.5		2	18	99
9.5			3	56
4.75				3

2) Chemical Stone (0 x 6.3 mm)	- 96% $CaCO_3$	100% minus 6.7 mm 72% minus 3.35 mm 40% minus 1.00 mm 16% minus 150 μm
3) Agricultural Limestone (Solpier)	- 92% $CaCO_3$	100% minus 3.35 mm 80% minus 850 μm 41% minus 150 μm
4) Pulverized Limestone (Stalco)	-	99% minus 150 μm 85% minus 75 μm 70% minus 45 μm

3. PROCESS DESCRIPTION

3.1 Limestone Product Process Flow

The general limestone process flow sheet illustrated in Figure I is the one operated by the Domtar Joliette plant for the production of aggregates, agricultural stone and pulverized stone. Aggregate stone is produced by a crushing system comprising a series of crushers and screens leading ultimately to the classification of 19 mm stone and under.

In this operation three crushers are used while stone preparation for lime making uses two crushers to produce a minus 50 mm stone. This explains why the product of the primary crusher is screened at a size of 25 mm and the oversize is reduced by an additional crusher, identified as the tertiary crusher. The product of this crusher is mixed with the undersize before being classified into final sizes, mainly under 19 mm. The secondary crusher serves to close the circuit by processing the oversize (plus 19 mm) remaining from the classification operation.

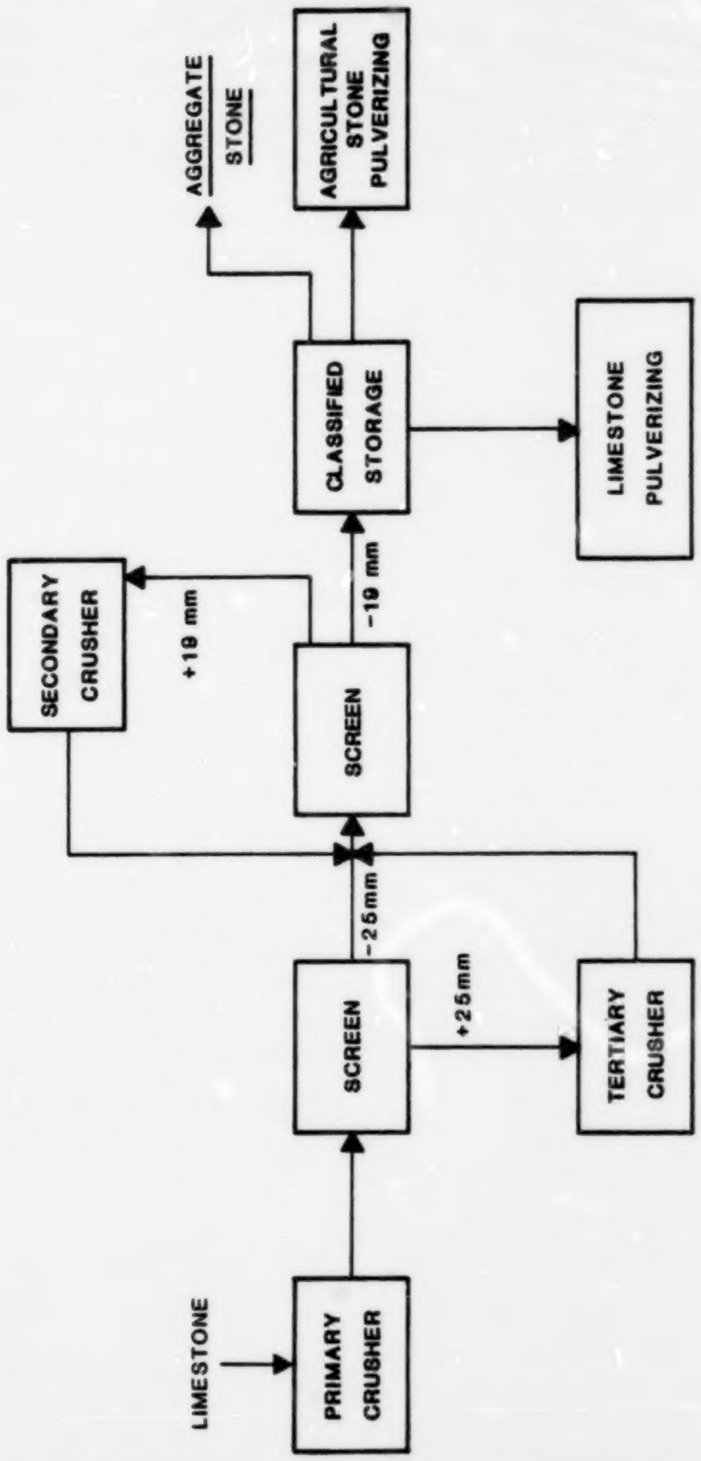
The minus 6.3 mm fraction is reclaimed from the classified storage and used as feed to the pulverizers that produce agricultural and pulverized stone.

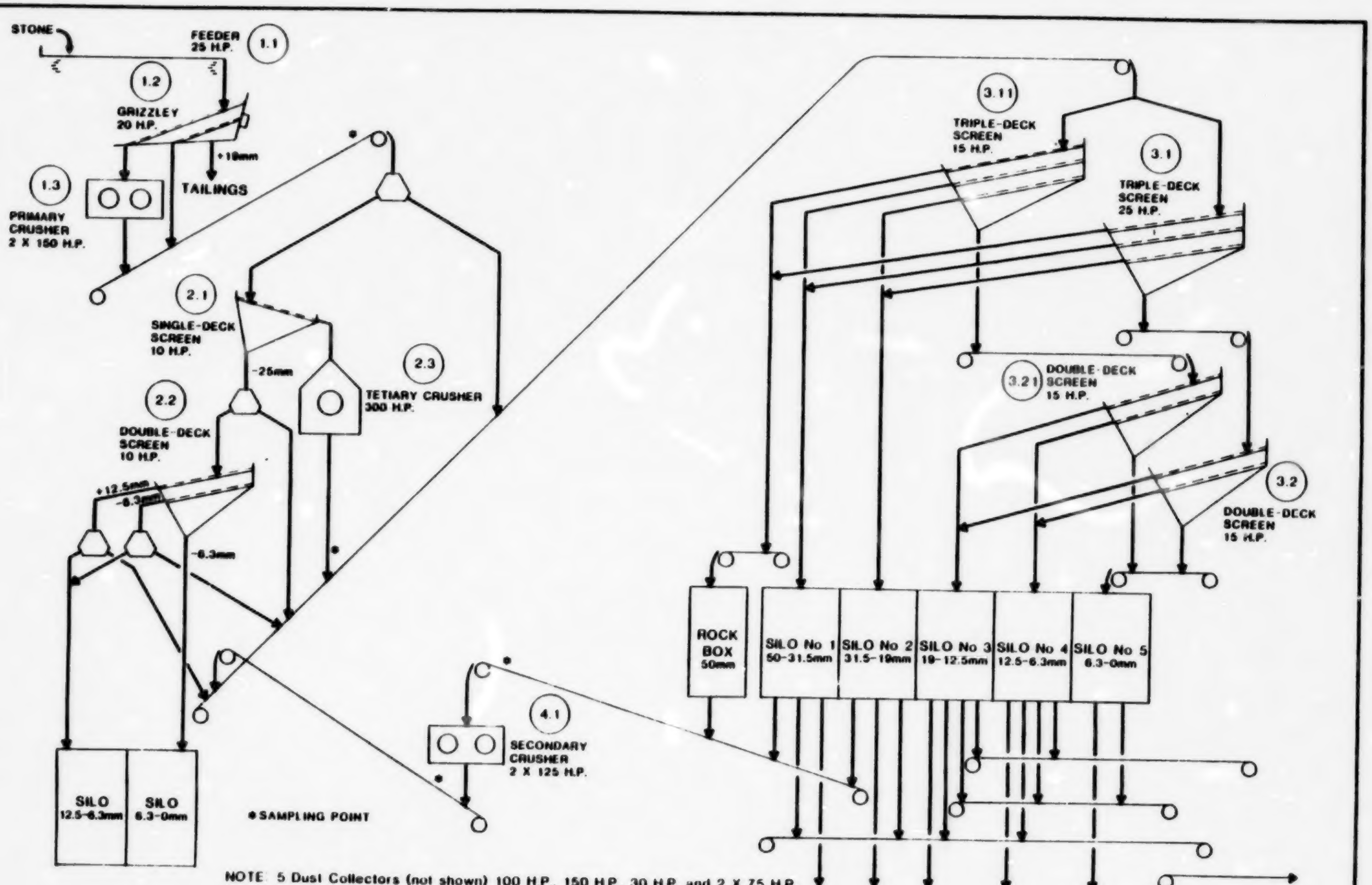
3.2 Aggregate Crushing and Classification

The limestone processing is illustrated by the flow diagram in Figure II. The equipment that was monitored during the survey is listed in Table 2.

Figure I - LIMESTONE PROCESS FLOW SHEET

DOMTAR JOLIETTE PLANT





NOTE 5 Dust Collectors (not shown) 100 H.P., 150 H.P., 30 H.P. and 2 X 75 H.P.

CANADA CEMENT LAFARGE LTD.
MONTREAL

DRAWN FGM DATE 20/04/83	**FIGURE II** **AGGREGATE CRUSHING & SCREENING FLOW DIAGRAM**	PLANT N PRODUITS CHIMIQUES DOMTAR - JOLIETTE, P.Q
CHECKED DCS DATE 20/09/84		PROJECT No. 20010

TABLE 2 - LIMESTONE CRUSHING AND SCREENING PLANT - EQUIPMENT LIST (COMMINUTION ONLY)

	EQUIPMENT	MOTOR	
No.	TYPE/MAKE/MODEL	HP	AMPS
1.1	RECIPROCATING FEEDER	25	24
1.2	VIBRATING GRIZZLY	20	20
1.3	PRIMARY CRUSHER: DOUBLE IMPELLER IMPACT BREAKER - CEDARAPIDS, MODEL 4350H	150 150	150 150
1.4	DUST COLLECTOR - 25,000 CFM	100	100
2.1	VIBRATING SCREEN - SINGLE DECK - 5' X 10' HEWITT-ROBINS M-11	10	10
2.2	VIBRATING SCREEN - DOUBLE DECK - 5' X 16' HEWITT-ROBINS M-11	10	10
2.3	TERTIARY CRUSHER - PULVOMATIC IMPACTORS - 48" 4000 VOLT	300	40
2.4	DUST COLLECTOR - 15,000 CFM	75	75
3.1	VIBRATING SCREEN - TRIPLE DECK - 5' X 16' HEWITT-ROBINS	25	25
3.11	VIBRATING SCREEN - TRIPLE DECK - 5' X 16' HEWITT-ROBINS	15	16
3.2	VIBRATING SCREEN - DOUBLE DECK - 5' X 16' HEWITT-ROBINS	15	16
3.21	VIBRATING SCREEN - DOUBLE DECK - 5' X 16' HEWITT-ROBINS	15	16
3.3	DUST COLLECTOR (SCREENING PLANT) 30,000 CFM	150	150
3.4	DUST COLLECTOR (CONVEYORS) - 5,000 CFM	30	30
4.1	SECONDARY CRUSHER: DOUBLE IMPELLER IMPACT BREAKER - CEDARAPIDS, MODEL 3645	125 125	125 125
4.2	DUST COLLECTOR - 15,000 CFM	75	75

Note: All motors are 550 volts, except where noted

Primary crushing is an open circuit composed of a reciprocating feeder, a vibrating doubledeck grizzly and a Cedarapids double impeller impact breaker, Model 4350H. The impact breaker is powered by two 150 HP motors. The large dust collecting capacity is powered by a 100 HP motor.

The primary crusher product is screened on a single deck screen having a 25 x 50 mm aperture. The oversize is reduced in a 48" Pulvomatic impactor powered by a 300 HP motor and identified as the tertiary crusher because it is only used when producing construction stone.The undersize can be screened again on a double deck screen for immediate storage of finished product (in that case, usually 6.3 x 12.5 mm and minus 6.3 mm stone). Generally, this double deck screen is not operated and the undersize of the single deck screen is conveyed to the main screening plant along with the tertiary crusher product. A dust collector fan powered by a 75 HP motor covers the needs in that area.

At that point the stone is all under 75 mm and it will be classified into five size fractions and stored in 180 tonne silos. The stone classification is effected by dividing the flow between two sets of two screens, the first being a triple deck and the second a double deck. The stone sizes are given in Figure II. The oversize fraction (plus 50 mm) excluded from storage is fed to a Cedarapids double impeller impact breaker, Model 3645, powered by two 125 HP motors. This crusher is identified as the secondary crusher because it is always kept operational, even when preparing stone for lime making, and is used to close the circuit with the screening plant. The coarsest sizes in the storage silos, i.e. the 31.5 x 50 mm and the 19 x 31.5 mm, are generally recirculated and added to the 50 mm oversize as feed to the secondary crusher. Trucks are also used to convey part of that stone back to the feed box of the primary crusher.

In that last portion of the crushing circuit three dust collectors are used with a total installed power of 255 HP.

The limestone crushing and screening circuit is capable of producing construction-type stone at a rate of over 400 tonnes per hour. This throughput, it must be noted, is dependent on the truck fleet transporting rocks from the quarry (four trucks were in use during the period of observation).

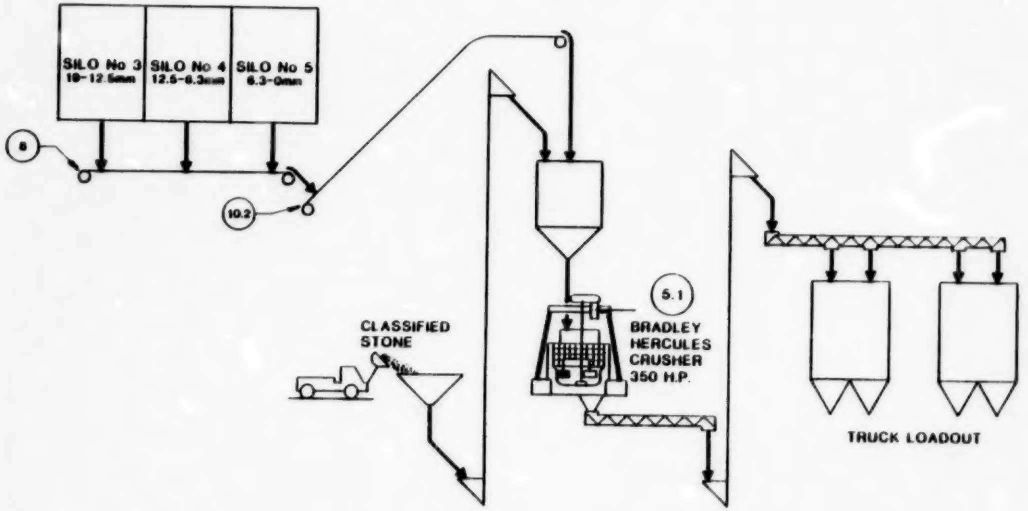
3.3 Limestone Pulverizing

Limestone pulverizing at the Joliette plant is rather a simple operation and could be termed more properly coarse grinding. Two types of products are involved, the agricultural stone and the pulverized stone marketed respectively under the names of "Solpier" and "Stalco". These products are obtained from two grinding plants whose flow sheets are illustrated in Figure III and Figure IV. The equipment involved is listed in Table 3.

TABLE 3 - Limestone Pulverizing Plants

EQUIPMENT		MOTOR	
No.	TYPE/MAKE/MODEL	HP	AMPS
5.1	Bradley Hercules - Type 6000 - 4000 Volts	350	51
5.2	Dust Collector (10,000 CFM)	25	25
6.1	Giant Griffin - 40" (x 2)	100 125	110 130
6.2	Dust Collector	40	40

Note: All motors are 550 volt, except where noted.



NOTE: Dust Collector (not shown) 25 H.P.

CANADA CEMENT LAFARGE LTD.
MONTREAL

DRAWN FGM
DATE 03/10/83
CHECKED DCS
DATE 20/09/84

FIGURE III
LIMESTONE PULVERIZING (SOLPIER)
FLOW DIAGRAM

PLANT PRODUITS CHIMIQUES
DOMTAR - JOLIETTE, P.Q

PROJECT No. 20010

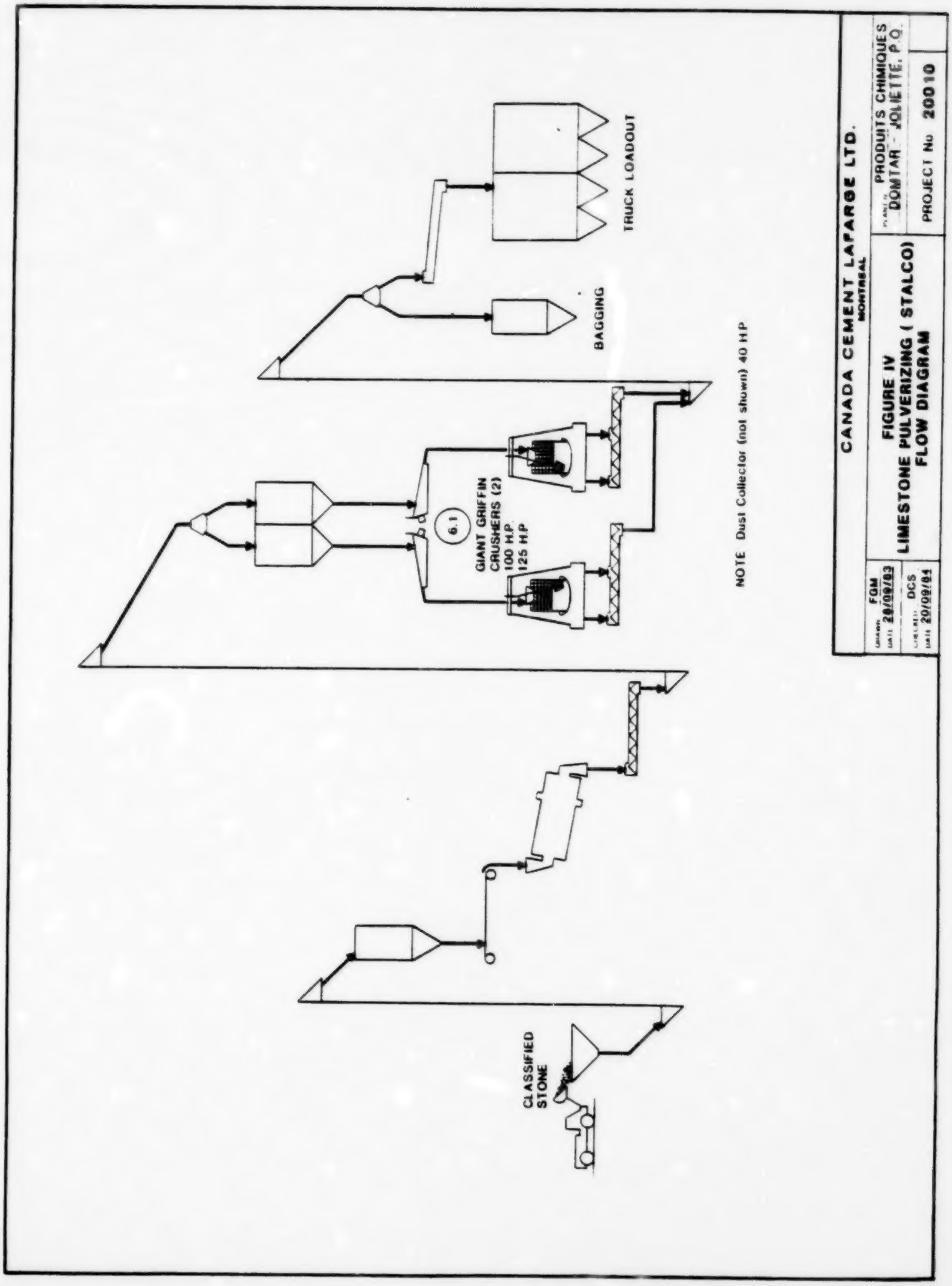


FIGURE IV
LIMESTONE PULVERIZING (STALCO)
FLOW DIAGRAM

CLASSIFIED STONE
6.1
GIANT GRIFFIN CRUSHERS (2)
100 H.P.
125 H.P.
NOTE Dust Collector (not shown) 40 HP
BAGGING
TRUCK LOADOUT
CANADA CEMENT LAFARGE LTD.
MONTREAL
DRAWN FGM
DATE 20/09/83
CHECKED DCS
DATE 20/09/84
PLANT PRODUITS CHIMIQUES DOMTAR - JOLIETTE, P.Q.
PROJECT No 20010

4. RESULTS AND DISCUSSION

The results of the data collection campaign are grouped under the following headings: aggregate crushing and screening, agricultural stone pulverizing and filler product pulverizing.

4.1 Aggregate Crushing and Screening

4.11 Electrical Measurements

A summary of the electrical measurements obtained on the aggregate crushing and screening circuit is presented in Table 4.

TABLE 4 - Aggregate Crushing and Screening

No.	EQUIPMENT	MOTOR HP	POWER OBSERVATIONS-kW		
			MAX.	MIN.	AVG.
1.1	Feeder	25	8	1	2
1.2	Grizzly	20	8	8	8
1.3	Primary Crusher	150	267	6	74
		150	204	6	98
1.4	Dust Collector	100	48	48	48
2.1	Single-Deck Screen	10	5	5	5
2.3	Tertiary Crusher	300	365	50	195
2.4	Dust Collector	75	51	51	51
3.1	Triple-Deck Screen	25	8	8	8
3.11	Triple-Deck Screen	15	5	5	5
3.2	Double-Deck Screen	15	6	6	6
3.21	Double-Deck Screen	15	5	5	5
3.3	Dust Collector (Screen)	150	51	51	51
3.4	Dust Collector (Conveyor)	30	16	16	16
4.1	Secondary Crusher	125	66	48	54
		125	36	30	33
4.2	Dust Collector	75	28	28	28

The power level observations for the primary and secondary crushers, and for the screening plant dust collector, were obtained by recording each motor power demand during sufficiently long periods. Concerning the tertiary crusher, the average three-phase current was recorded.

An interesting comparison can be made between this set of observations and that of the circuit operation when preparing stone for lime making (see the report on the Lime Industry which presents the results of a previous data collection campaign). Table 5 presents such a comparison between the two crushing operations in terms of electric loading of the crusher motors (in percentage of nominal power).

TABLE 5 - Crusher Motor Load (% Nominal Power)

CRUSHER	AGGREGATE STONE (JUNE '83)	LIME MAKING STONE (APRIL '83)
Primary	76.9	94.7
Secondary	46.6	24.7
Tertiary	87.1	-

- The primary crusher feed is coarser in the case of the lime making stone than in that of the aggregate stone. The lime making stone is apparently harder to crush than the aggregate stone. Both factors combine to induce a higher power demand on the primary crusher.

- The product size aimed at for lime making (minus 50 mm) being already obtained for over 70% of the primary crusher product, little work is left for the secondary crusher.

- Conversely, for the aggregate stone, the product size aimed at (minus 19 mm) is obtained for only 35% of the primary crusher product; the tertiary crusher does most of the work as shown by the 87% loading and, this time, more work is left for the secondary crusher.

The power demand for dust collectors totals 194 kW, which is 13% more than observed for the lime making stone (172 kW). This increased power demand is caused solely by the two dust collectors at the screening plant, particularly the screens dust collector (51 vs 32 kW).

4.12 Flowrates

The flowrate of the aggregate crushing and screening circuit was determined by using the quarry truck loads.

Two eight-hour production shifts on June 2, 1983, were used to determine the production rate. The count of trucks during a shift is multiplied by the average truckload weight (established by weighing randomly 6 to 9 trucks) to give the overall shift production. The total production for these two shifts is listed below.

DATE	PRODUCTION (tonnes)
June 2 7-15 hour shift	2970
June 2 15-23 hour shift	2822

The average production rate of the crushing operation over the hours operated (14.33 h) was calculated at 404.1 t/h. But the actual production rate, when the primary crusher is continuously fed, is estimated at 680 t/h. Thus the average production rate represents a utilization factor of about 60% of the potential flowrate.

The determination of flowrates at other points in the circuit is based on a sampling plan which consisted of four simultaneous belt-cut samplings effected on conveyors 1, 2, 6 and 7. The samplings characteristics and the flowrates thus calculated are shown in the following table.

TABLE 6 - Material Sampling

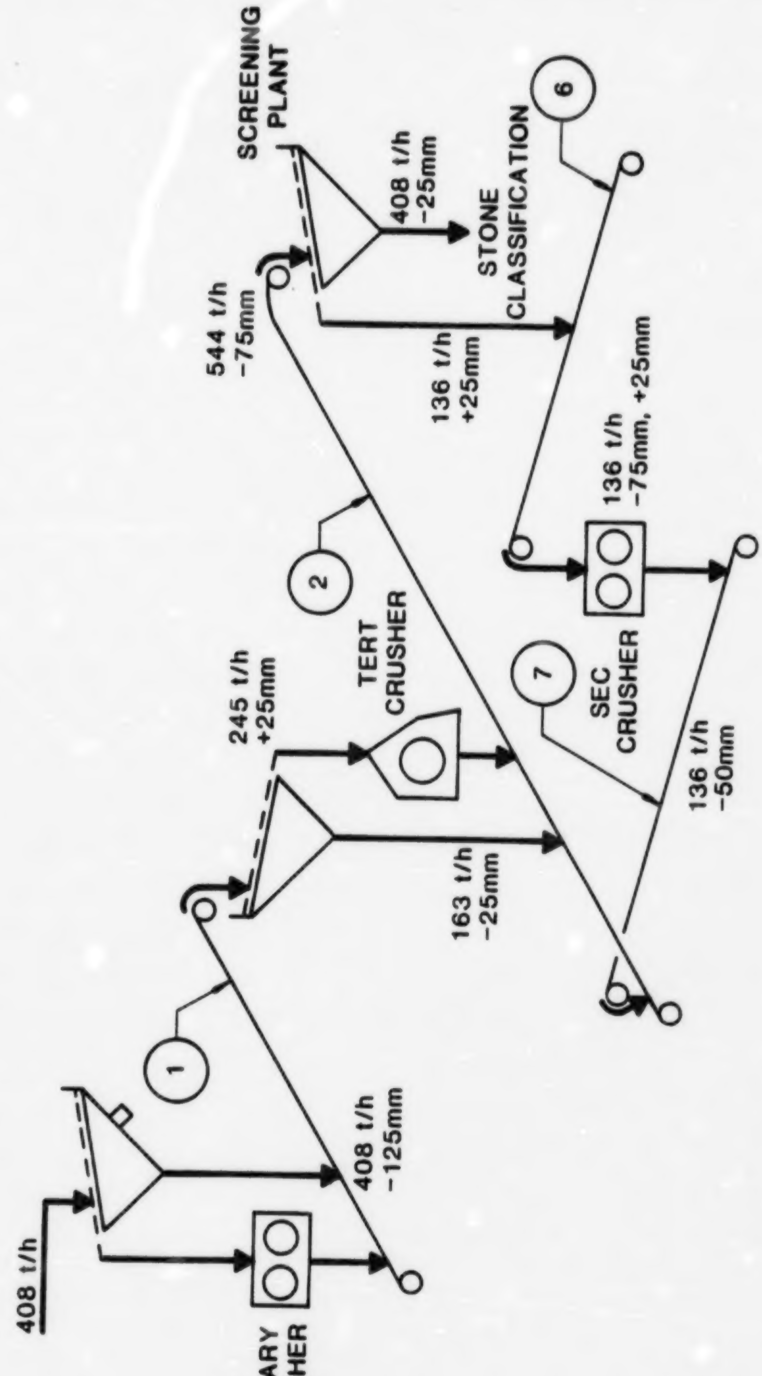
SAMPLING	CUT LENGTH	SAMPLE WEIGHT	BELT SPEED	MATERIAL FLOWRATE
POINT	m	kg	m/min	t/h
C-1	1.829	166.5	117.7	642.6
C-2	0.914	61.7	135.6	549.5
C-6	1.219	20.5	128.0	129.0
C-7	1.219	24.0	137.2	162.0

These calculated flowrates can be considered as close to average situation with the exception of the one found on conveyor C-1. The latter one can be explained by a sudden surge of material caused by a higher than average truck arrival rate, the circuit having been stopped under full load before a lunch break. This flowrate is confirmed by the fact that 7 truckloads were delivered to the primary crusher during the half-hour period preceding the circuit stoppage. If three truckloads were crushed during the last ten minutes, it would be equivalent to a flowrate of 607 t/h. The flowrate sampled on conveyor C-1 reinforces the view that the primary crusher can process up to 680 t/h as stated above.

Concerning the other calculated flowrates, the one found on C-2 is felt to be representative of the screening plant feed rate. But a sizeable discrepancy exists between the C-6 and C-7 flowrates which should represent the flowrate through the secondary crusher: this situation results probably from the surge condition observed at the primary crusher which was creating unstable flow conditions. The true average flowrate is necessarily between these two rates and, based on the study of the size distributions available, it is estimated at 136 t/h. This flowrate includes the recirculation of the stone screened and stored in silo No. 1 (31.5 x 50 mm) which makes up the greater part of this flow (about 80%).

To summarize the description of flowrates, a typical circuit operation is outlined in Figure V, showing average flowrates and sizes. A simplification is made by choosing arbitrarily a 25 mm mesh for the screening plant and the screen before the tertiary crusher. This dimension is thought to be closer to the true separation size of the actual 25 x 50 mm and 31.5 mm aperture screens. A circulating load estimated at 136 t/h comprises the recirculation of the stone stored in silo No. 1. The stone trucked from silo No. 2 to the primary crusher feed is not taken into account.

Figure V - AGGREGATE STONE PRODUCTION TYPICAL CIRCUIT OPERATION DIAGRAM



- AVERAGE PRODUCTION FLOWRATE: 404 t/h

4.13 Size Distribution

The June 2-day shift production breakdown data (not reported here in detail) was used to derive a typical product size distribution for the crushing circuit. This distribution is given in the following table.

CRUSHING CIRCUIT TYPICAL PRODUCT SIZE DISTRIBUTION	
mm	% Passing
50.0	100
31.5	98.2
19.0	96.7
12.5	62.7
6.3	32.4

The size distribution of the primary crusher feed was minus 900 mm, plus 50 mm and mainly minus 450 mm, plus 150 mm.

The primary crusher production was sampled on conveyor C-1 as described earlier. The secondary crusher feed and product were also sampled on conveyors C-6 and C-7, respectively. But it was not feasible, due to production constraints, to sample the tertiary crusher feed and product; the size distributions for the latter have been estimated. The size distributions for the above mentioned steps in the comminution processes are grouped in Table 7.

The four size distributions that were determined at the Joliette plant laboratory are shown in working papers.

Data is given in Table 8 on the screening equipment being used to effect the classification of aggregates. The screens are identified by their equipment number as illustrated in Figure II.

TABLE 7 - Aggregate Crushing & Screening Circuit Size Distributions

mm	PRIM. CRUSHER PRODUCT % passing (1)	TERT. CRUSHER FEED % passing (2)	TERT. CRUSHER PRODUCT % passing (2)	SEC. CRUSHER FEED % passing (1)	SEC. CRUSHER PRODUCT % passing (1)
132.5	100	100			
100	96.1	93.5			
90	92.4	87.3		100	
75	88.9	81.5	100	98.4	100
63	84.3	73.8	95.6	95.9	97.3
50	74.3	57.2	93.3	82.0	95.2
38.1	61.1	35.2	86.0	70.1	92.8
25.0	43.6	6.0	55.3	3.9	64.0
19.0	34.4		38.3	1.4	47.6
12.5	25.2		24.8	1.0	33.2
9.5	20.3		18.1	0.9	25.9
4.75	11.8		8.7	0.8	14.3

(1) Sieve Analysis Tested
(2) Estimated

TABLE 8 - Screens Characteristic Data

EQUIPMENT No.	SCREEN DIMENSIONS m	APERTURE mm	WIRE DIAMETER mm	OPEN AREA %
2.1	1.52 x 3.05	25 x 50	9.53	61.2
2.2	1.52 x 4.88	12.5 x 12.5	4.50	54.5
-	-	6.3 x 6.3	2.03	57.4
3.1	1.52 x 4.88	50 x 50	11.12	67.3
-	-	31.5 x 31.5	9.53	59.2
-	-	19.0 x 19.0	5.26	61.4
3.2	1.52 x 4.88	12.5 x 12.5	4.50	54.5
-	-	6.3 x 6.3	2.03	57.4

4.14 Grindability Testing

The grindability testing by both the Hardgrove and Bond test procedures as conducted at the CCL Belleville laboratory. A chemical analysis was also made to ascertain that the tested limestone was really the aggregate stone with over 4% SiO_2 content (the so-called "Pierre Noire").

The Hardgrove Index (HGI) found on this limestone is 66 which is appreciably less than the value found on the lime making stone (83). The Bond Index gave a test value of 8.41 kWh/T, lower than the value found in the lime making stone (8.86 kWh/T). The calculated Bond Index was 9.61 kWh/T.

These results suggest that this limestone has a normal Work Index. For instance, a typical HGI value would be in the range of 50-70 giving an average computed Bond Index of 10.5 kWh/T. Relying on the HGI found, the aggregate stone would be harder to grind than the lime making stone (the so-called "Pierre Grise"), but this fact does not necessarily imply that it is also harder to crush; the opposite could well be the case.

4.15 Specific Energy Consumption

The procedure used to calculate the specific energy consumption consists simply in adding up the average power demand of each motor and dividing this total power demand by the average production rate. But, in the case of a crushing operation fed irregularly by truckloads, some caution is required in using the average power demand of a crusher motor as observed on power charts. The average power demand observed is not a true representation of power consumed during a full hour of production: this is due to idle running when no feed is supplied to the primary crusher. The observed power demand must therefore be adjusted down to take into account the non-productive time: the utilization factor (see Section 4.12) is used to this effect. Another equivalent approach would be to use the potential flowrate as the true instantaneous production rate. This adjustment concerns only the primary crusher.

Accordingly, the average power demand of the primary crusher totalling 172 kW when fully loaded is adjusted by the utilization factor of 0.60 to 103.2 kW. This value is then added to the secondary and tertiary crushers power demand (282 kW) and the total divided by the average production rate (404.1 t/h) to give a figure of 0.953 kWh/tonne for crushing only.

To this figure must be added the specific consumption of all other motors (auxiliaries) which is obtained by dividing the total non-crushing average power demand by the average production rate. This amounts to 0.576 kWh/tonne. The total circuit specific consumption, the sum of these two figures, is 1.53 kWh/tonne.

Table 9 summarizes the data developed above and Table 10 gives a distribution of power consumption between crushing, screening and dust collecting.

TABLE 9 - Aggregate Crushing and Screening
Specific Power Consumption

	kWh/tonne	%
Crushing Only	0.953	62.2
Auxiliaries	0.577	37.8
Total	1.53	100.0

TABLE 10 - Aggregate Crushing and Screening
Distribution of Consumption

	%
Crushing Only	62
Screening	7
Dust Collecting	31

The specific consumption for crushing alone (0.953 kWh/t) is comparable to other limestone crushing operations. In cement manufacture, a figure around 1.0 kWh/t is common for a reduction to minus 19.0 mm.

4.2 Agricultural Stone Pulverizing

4.21 Electrical Measurements

At the time of the survey, the agricultural stone pulverizing plant was not operational and as a consequence the Bradley 6000 Hercules pulverizer could not be monitored.

But typical operating electrical values were obtained from plant records; the data is presented in Table 11. The power factor values used to calculate the power consumption of the pulverizer and dust collector were 0.75 and 0.65, respectively.

TABLE 11 - Agricultural Stone Pulverizing

No.	EQUIPMENT	MOTOR HP	POWER OBSERVATIONS - kW		
			MAX.	MIN.	AVG.
5.1	Bradley 6000 Hercules	350	260	260	260
5.2	Dust Collector	25	9	9	9

From these values the Bradley pulverizer appears fully loaded and the dust collector power demand very low.

4.22 Flowrate

According to plant records, the production rate of the pulverizer is very steady and of the order of 41 t/h. This value is used to compute the specific power consumption.

4.23 Size Distribution

The feed to the pulverizer can be supplied from any of the silos No. 3, No. 4 or No. 5, with the last being the usual source. The size distributions for silos No. 3 and No. 4 were previously described in Table 1 under the 12.5 x 19.0 mm and 6.3 x 12.5 mm headings. Silo No. 5 size distribution is described briefly in the same table under the heading of Chemical Stone. But a more complete distribution is given below.

BRADLEY PULVERIZER FEED SIZE DISTRIBUTION	
mm	% Passing
6.7	100
4.75	86
3.35	72
2.36	58
1.18	40
0.600	29
0.300	24
0.150	16
0.075	12

As for the pulverizer product size, a partial distribution was given in Table 1 under the heading of Agricultural Limestone, but more details are given in the following table:

AGRICULTURAL STONE SIZE DISTRIBUTION	
mm	% Passing
3.35	100
2.36	99
1.70	94
0.850	80
0.250	52
0.150	41

4.24 Specific Energy Consumption

The electrical data reported in Table 11 and the production rate in 4.22 are used to compute the specific power consumption data for the pulverizer circuit and the cumulative consumption which is shown in Tables 12 & 13.

TABLE 12 - Agricultural Stone Pulverizing Circuit Specific Power Consumption

	kWh/tonne	%
Pulverizing	6.37	96.5
Dust Collecting	0.23	3.5
Total	6.60	100.0

TABLE 13 - Agricultural Stone Cumulative Power Consumption

	kWh/tonne	%
Crushing	0.95	11.6
Pulverizing	6.37	78.4
Auxiliaries	0.81	10.0
Total	8.13	100.0

The specific consumption for pulverizing alone is the energy consumed by the Bradley pulverizer while the term "pulverizing and crushing" is the total finished product energy consumption. The comminution work makes up 90% of the combined pulverizing and crushing consumption.

The performance of the Bradley pulverizer can be rated as excellent for the comminution work done. Its electrical load is maximum at 260 kW (almost 350 HP) and its production rate is most probably at a maximum at almost 41 t/h. This performance compares very well with past performances reported in Taggart's Handbook of Mineral Dressing for a similar mill grinding cement rock to minus 1.18 mm at 36.3 t/h with a 300 HP motor: the specific consumption amounted in that case to 6.2 kWh/tonne.

4.3 Filler Product Pulverizing

4.31 Electrical Measurements

One of the two Giant Griffin mills was monitored using the recording wattmeter. The electrical measurements are presented in Table 14. The dust collector is used by both mills; its power demand must be halved to calculate the consumption for a single mill.

TABLE 14 - Filler Product Pulverizing

No.	EQUIPMENT	MOTOR HP	POWER OBSERVATIONS - kW		
			MAX.	MIN.	AVG.
6.1	Giant Griffin	100	73	66	72
6.2	Dust Collector	40	14	14	14

From these power observations it is obvious that the Griffin mill operates fully loaded. By observing the amperage on the second Griffin mill it could be seen operating at the same loading for an equivalent production.

4.32 Flowrate

Production rate on each Griffin mill was reported to be very steady at 4.5 t/h. This value is used to compute the specific power consumption.

4.33 Size Distribution

The feed to the Griffin mill is the minus 6.3 mm stone obtained from silo No. 5 and of which the size distribution was given in 4.23.

A partial description of the product size distribution is given in Table 1 under the heading of Pulverized Limestone. Sedigraph analysis indicated that, at that time, the product was coarser than specifications: the minus 150 µm was 91% instead of 99%, the 75 µm was 74% instead of 85% and the 45 µm was 59% instead of 70%.

4.34 Specific Energy Consumption

The electrical data reported in Table 14 and the production rate in 4.32 are used to compute the specific power consumption data for the circuit and cumulative consumption for the product which are shown in Tables 15 & 16.

TABLE 15 - Filler Product Pulverizing Circuit Specific Power Consumption

	kWh/tonne	%
Pulverizing Only	15.9	91.4
Dust Collecting	1.5	8.6
Total	17.4	100.0

TABLE 16 - Filler Product Cumulative Power Consumption

	kWh/tonne	%
Crushing	0.95	5.1
Pulverizing	15.90	84.1
Auxiliaries	2.05	10.8
Total	18.9	100.0

The comminution work makes up 89% of the combined pulverizing and crushing consumption.

The performance of the Giant Griffin mills can also be rated as excellent, their electrical load being almost a maximum at 72 kW and the production rate at 4.5 t/h each. The Handbook of Mineral Dressing reports, for a similar type of mill grinding limestone to 95% passing 150 µm and using a 75 HP motor, a production rate of 3.2 t/h and a specific power consumption of 17.6 kWh/tonne.

The power consumption for total comminution, including auxiliaries, is low in the limestone processing operations of the Joliette plant reflecting the preponderance of aggregate production and low volumes of coarse grind products. In specific terms, it ranges from 1.5 kWh/tonne for aggregates classified in three sizes (19.0, 12.5, 6.3 mm) to 8.1 kWh/tonne for agricultural stone and 18.9 kWh/tonne for the filler product (90% passing 150 µm).

The cost involved is not a major factor in the manufacturing cost, particularly in the case of aggregates where it accounts for less than 5%. For the agricultural stone, the cost for comminution, including auxiliaries, represents less than 10% and for the filler product, the cost is about 15% of manufacturing cost.

In all cases, the potential for savings is small. This is particularly true for the two pulverizer operations where the grinding machines are used at full power and production rates have reached close to optimal rates at almost 41 t/h for agricultural stone and 4.5 t/h per mill for filler product. It is not as true in the case of the crushing circuit where the production rate could be somewhat higher by increasing further the utilization factor. Admittedly, this suggestion would have to be examined closely in relation to the screening and conveying capacity.

A possible improvement may be sought in the increase of throughput because the crusher motors have still some power margin left. Although this survey and its associated field work were not conducted during a period long enough to identify properly the circuit bottleneck, the scalping screen before the tertiary crusher and the tertiary crusher itself would appear to be the probable source of throughput limitation. The tertiary crusher was found highly loaded at 87% of nominal power and the scalping screen in the same situation due to its limited screening area (4.5 m^2).

A possible approach to ease these constraints may be to enlarge the screen opening in order to decrease the feed to the tertiary crusher and the loading on the motor at the present operating level. This change would transfer more work onto the secondary crusher which is the least loaded. As a consequence, the circuit overall throughput could be increased somewhat in the future subject to conveying capacity and quarry truck availability. The loading on motors of conveyors C-1 and C-2 at present operating level would have to be checked for spare capacity to ensure the feasibility of throughput increase.

STEEP ROCK RESOURCES INC. CALCITE PLANT

AT PERTH, ONTARIO

STEEP ROCK CALCITE
A DIVISION OF STEEP ROCK RESOURCES INC.

1. THE COMPANY*

1.1 General

Steep Rock Resources Inc. owns a calcite quarry property at Tatlock, Ontario, and a calcite processing plant at Perth, Ontario. The deposit is unique in its combination of favourable characteristics: magnitude, whiteness, high calcium content, low magnesium and silica contents, and scarcity of accessory minerals.

The Perth plant processes, in fact, a white marble which is crushed, dried, screened, dry ground and air classified into a wide range of products, from decorative stone chips to white fillers and extenders used in paint, plastic and joint compounds.

When Steep Rock Resources purchased this operation from W.R. Barnes Company Ltd. in December 1980, the main elements of the plant were a primary crusher, two screen-houses, a rotary dryer, a fine grinding section containing a 66-inch Raymond roller mill, air classifiers, bagging and bulk loadout facilities, and a warehouse.

A major expansion of the fine grind production capacity was undertaken in 1982 and put into production in mid 1983. This expansion provides greater flexibility as to product mix and reduces dependence on a single grinding equipment, the Raymond mill. In fact, before expansion, the Raymond mill system was producing through its integrated air classifiers four different products with particle top sizes of 76, 44, 25 and 15 µm, respectively. This system had necessarily a limited capacity to produce the finest sized and highest value products. After expansion, the dependency on the Raymond mill was removed by adding a new grinding circuit consisting essentially of a pebble mill with an integrated air separator, two high efficiency air classifiers, a new bulk loadout facility and other auxiliary equipment. This new pebble mill can accept feed directly from the second screenhouse and thus operate in parallel with the Raymond mill. But, generally, the latter produces a coarser product at a much higher and more efficient rate for further grinding in the pebble mill.

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* The information in this section is derived from a paper given at the 19th Forum on the Geology of Industrial Minerals, Ontario, Geological Survey, 1983.

The plant expansion provides a doubling of fine and medium fine grinding capacity allowing to satisfy projected market demand for these products. The expansion has been designed to be fully compatible with a possible future move into production of ultrafine calcite products.

1.2 Products

Three types of products are made: aggregate stone, screened sand-grade products, and fine and medium-fine grind products.

Aggregate products are the coarsest in size and the lowest in value, ranging from 16 by 31.5 mm down to minus 3.2 mm size. Typical uses for these products are decorative chips and driveway stone, terrazo chips, poultry grit and white block manufacturing.

Screened sand-grade products have finer sizes, ranging from 600 by 2400 µm to 75 by 425 µm. Typical uses include animal feed, stucco mix, cultured marble, floor tile and ashtray sand.

Fine and medium-fine grind products have the smallest particle size and highest value. The coarsest medium-fine grind product is 80% minus 45 µm. The finest of the present fine grind products has a particle top size of 15 µm. These products are used as fillers in paint, plastics, rubber, joint compounds, adhesives and other industrial products.

2. PROCESS DESCRIPTION

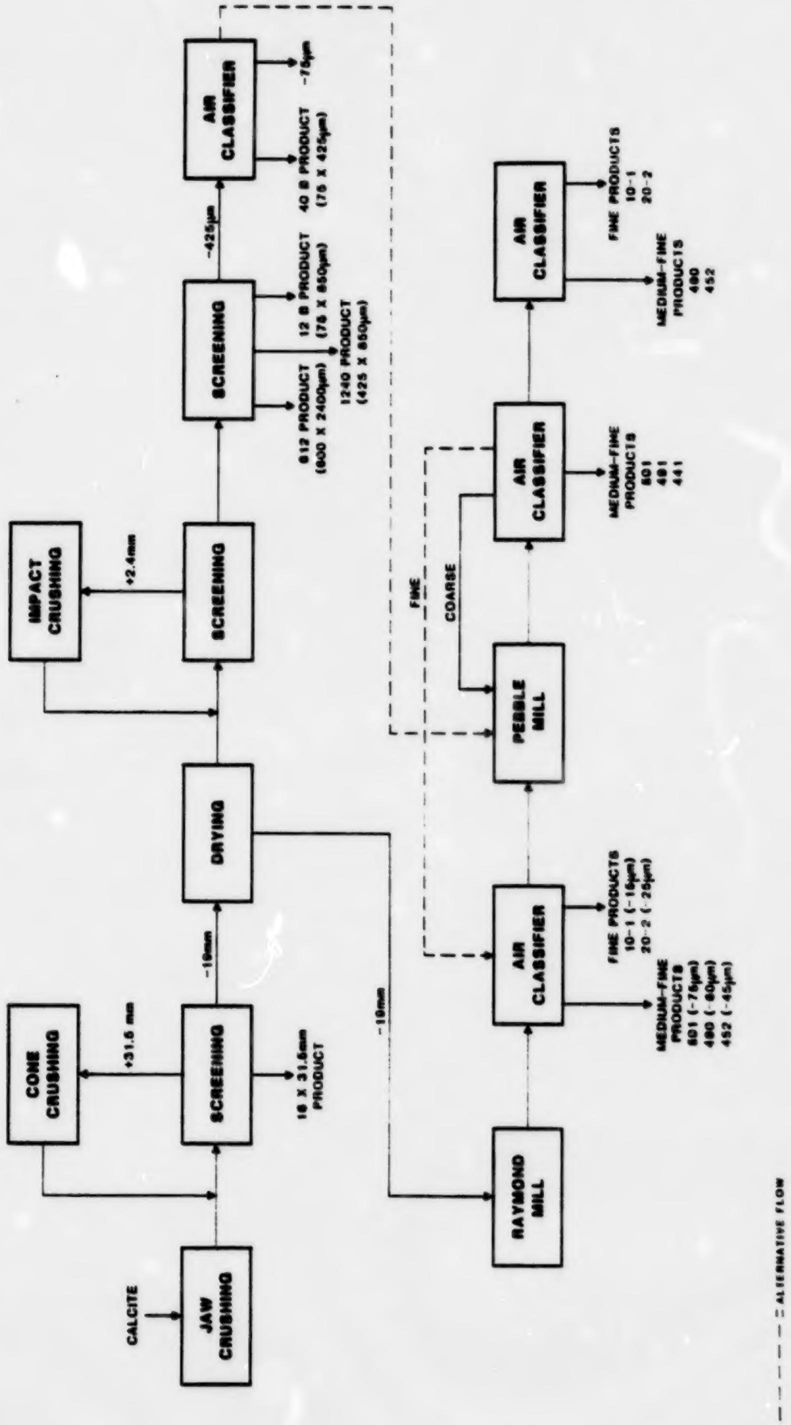
The calcite processing flowsheet of Steep Rock is shown in Figure I. Primary and secondary crushing is done at the Tatlock quarry. The rock is fed to a jaw crusher and the product screened on double-deck screens to remove the 16 by 31.5 mm saleable product and the minus 19 mm. The oversize is reduced further in two cone crushers operating in parallel and closing the circuit with the screens. Other aggregate sizes can also be produced at the quarry.

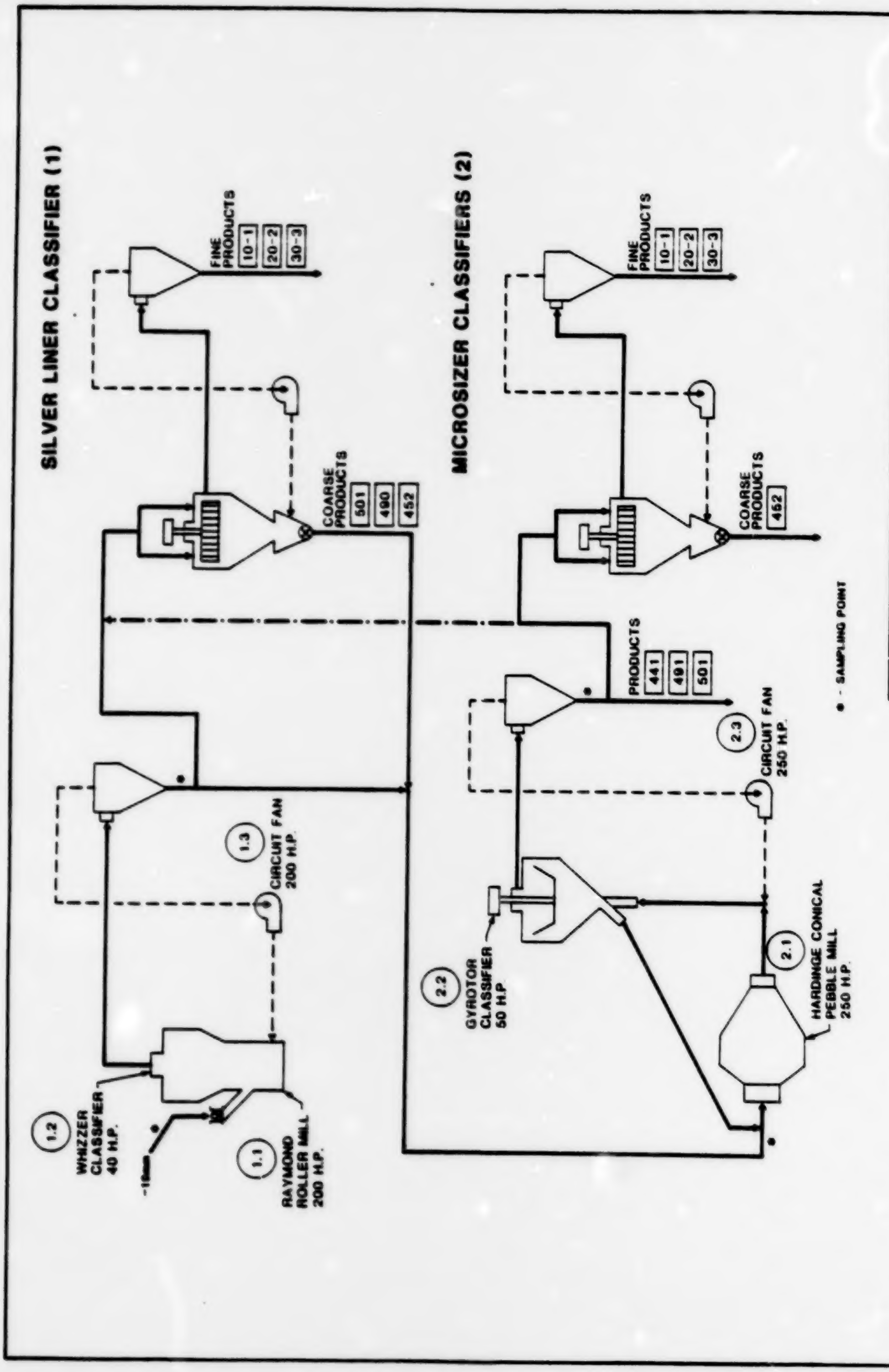
The minus 19 mm ore is trucked approximately 40 km to the Perth plant. The ore is dried, screened and air classified to produce the sand-grade products. To this end two stages of screening and one of air classification are used. The oversize of the first screen (+2.4 mm) is reduced in an impact crusher operating in closed circuit. The undersize is further screened on a double-deck screen sizing the coarser products. The undersize of the second screen is fed to an air classifier to size the finer sand-grade products. It can also be used as an alternative feed to the pebble mill.

The two grinding circuits illustrated in Figure II allow the production of the fine and medium-fine products. The standard operating practice is to feed the Raymond mill with the dried minus 19 mm ore to make the coarser 501 product (-75 μm) which serves as feed to the pebble mill. The pebble mill discharge is classified by the integrated Gyrotor air classifier which returns the coarse to the mill feed. The Gyrotor fines are further classified in two "Micro-Sizer" high efficiency air classifiers to produce the range of fine and medium-fine products. With this scheme, the production of finer products is maximized.

Figure I - CALCITE PROCESS FLOW SHEET

STEEP ROCK CALCITE PERTH, ONTARIO





CANADA CEMENT LAFARGE LTD.
MONTREAL

FIGURE II - CALCITE GRINDING
RAYMOND & PEBBLE MILL CIRCUITS
FLOW DIAGRAM

DRAWN GFJ
DATE 30-05-84
CHECKED DCS
DATE 20/09/84
PLANT Nº
PROJECT No. 20010

Alternatively, the two grinding mills can be fed separately, thus providing greater flexibility to produce the same product range. The Gyrotor fines of the pebble mill circuit can even be conveyed to the Raymond mill air classifier for added flexibility.

The energy consumption of both grinding circuits will be hereafter examined in a typical operating condition. The study pertains only to each mill and its integrated classifier as exemplified by the material samples taken in both circuits for particle size distribution determination.

3. ENERGY CONSUMPTION

3.1 Electrical Measurements

A summary of the electrical measurements obtained on the Raymond and pebble mill circuits is presented in Table 1.

TABLE 1 - Electrical Measurements

		MOTOR HP	MEASUREMENTS		POWER DEMAND
No.	EQUIPMENT		VOLTS	AMPS	kW
1.1	Raymond Roller Mill-6669	200	560	180	140
1.2	Wizzer Classifier	40	560	20	14
1.3	Circuit Fan	200	560	105	76
2.1	Hardinge Conical Pebble Mill - 10' x 84"	250	-	-	112
2.2	Gyrotor Classifier	50	500 DC	30	15
2.3	Circuit Fan	250	-	-	112

For the Raymond mill, the amperage was read on ammeters, the voltage assumed and the power demand in kW calculated by assuming a power factor (P.F.) value of 0.8, 0.7, and 0.75 for the respective motors (1.1, 1.2, 1.3). The pebble mill and fan motors' kW demand was derived from readings on kW meters scaled 0 to 100% of nominal power; on both motors the reading observed was 60%. For the classifier, the power demand is the product of the amps reading by the assumed 500 V DC.

3.2 Flowrates

The production rates for the respective mill circuits have been estimated to be as follows:

- Raymond mill (452 Product) : 5.44 t/h
- Pebble mill (441 Product) : 5.0 t/h

3.3 Size Distributions

Four material samples were taken as shown on flow diagrams (Figure II) and tested for particle size distribution. The samples represented the Raymond mill feed and product, and the pebble mill feed and circuit product (in the latter case, the Gyrotor classifier fines).

The size distributions determined are shown in Figure III. The complete distribution for the Raymond mill feed sample is given in Table 2. The test results for sieve analysis, Blaine and Sedigraph can be seen in the working papers.

TABLE 2 - Raymond Mill Feed Size Distribution

μm	% Passing
19 000	100
9 500	87.8
4 750	83.5
2 360	80.3
1 180	72.9
600	62.9
300	51.0
150	38.1
75	23.5
45	16.3

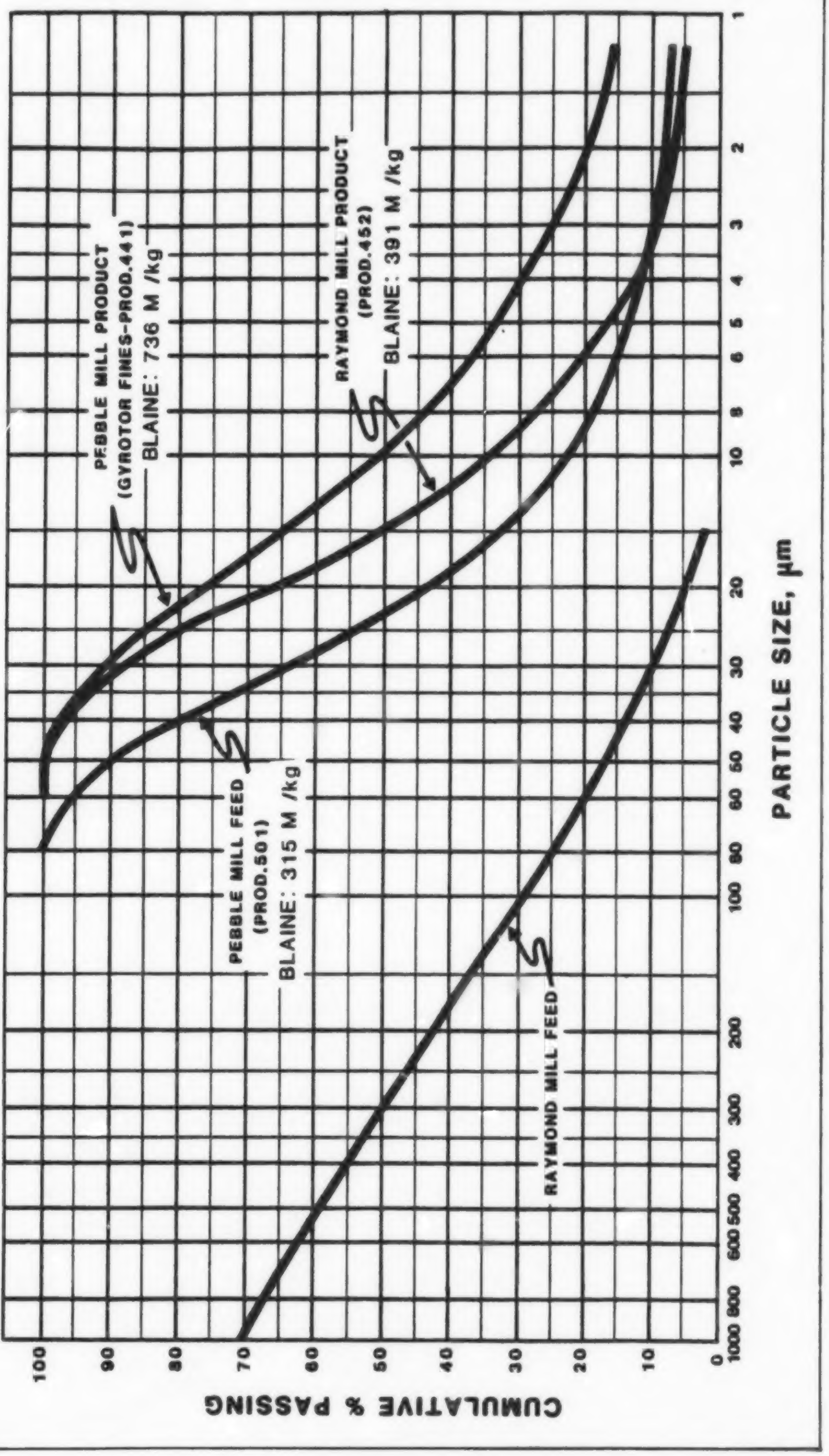


Figure III - CALCITE SAMPLE SIZE DISTRIBUTIONS

The size distributions determined on these samples are in good agreement with the data in Table 3, extracted from Steep Rock products data sheets, and confirm the products that were being made at the time of plant visit. The pebble mill product with a mean particle size of 10 µm was confirmed by the plant to be representative of the 441 product.

TABLE 3 - Medium-Fine & Fine Products Physical Properties

PROPERTY	501	452	20-2	10-1
Dry Brightness (Green Filter)	90	94	95.5	96
% Retained on 75 µm sieve	2.5	-	-	-
% Retained on 45 µm sieve	20.0	1.0	0.01	0.001
Mean Particle Size, µm	22	17	7.0	4.8
Bulk Density, g/l	1100	1007	882	802
Specific Gravity	2.71	2.71	2.71	2.71
Hardness, Mohs Scale	3	3	3	3

3.4 Specific Energy Consumption

Table 4 summarizes the specific power consumption determined for both circuits and expressed as consumption for grinding alone and total consumption including auxiliaries (classifier and circuit fan).

TABLE 4 - Calcite Grinding
Specific Power Consumption

	GRINDING ONLY	GRINDING & AUXILIARIES	COMMINUTION CONSUMPTION
	kWh/tonne	kWh/tonne	%
Raymond Mill (452 Product)	25.7	42.3	61
Pebble Mill (441 Product)	22.4	47.8	47

The pebble mill specific energy consumption data shown above does not account for the energy accumulated in the mill feed, which is the 501 product produced by the Raymond mill. But the 501 product specific energy consumption can be estimated with assumed kW values derived from Table 1 and a production rate of about 10.5 t/h. In fact, the power demand of the Raymond mill circuit should be expected to decrease by about 10% when producing the 501 product. Using this assumption, total circuit power demand would be 207 kW and the 501 product specific energy consumption would approximate 20 kWh/tonne of which 12 kWh/tonne could be attributed to grinding alone. Combining these data to those of the pebble mill (Table 4) gives a cummulative total specific energy consumption of around 68 kWh/tonne of pebble mill product (441 product). The comminution consumption alone amounts to about 34 kWh/tonne and represents 50% of total consumption.

The above determined specific consumptions appear valid and reasonable when compared to other reported data in the technical literature.

APPENDIX

INDUSTRY REVIEW

GENERAL INFORMATION

The Mineral and its Processing

Lime and limestone are frequently confused. Limestone is a general term embracing all carbonate rocks or fossils which are composed primarily of calcium carbonate ($CaCO_3$) or combinations of calcium and magnesium carbonates. It may contain varying degrees of impurities, the most common of which are silica and alumina. Lime, on the other hand, is derived from limestone through a burning process known as calcination, which expels carbon dioxide (CO_2) from the stone leaving lime (CaO, calcium oxide) according to the following formula:[1]

$$\underset{\text{limestone}}{CaCO_3} \xrightarrow{\text{heat}} \underset{\text{lime}}{CaO} + \underset{\text{carbon dioxide}}{CO_2}$$

The usual (albeit arbitrary) dividing line between limestone and any other type of rock is such that if the rock contains a total of 50% or more combined carbonates of calcium and magnesium, it is called limestone, if less, it is otherwise classified.[2]

Within the limestone group itself, there are three classes based on the relative proportions of its constituents, as shown in Table 1.

All limestone deposits contain some sandy or clayey material. "Pure" limestone is classified as having less than 5% total impurities. For commercial purposes, pure limestones are generally required. Therefore, the first classification system is considered more useful since it gives an actual percentage; while the second system, based on ratios, is viewed as more scientific because it accounts for the presence of different impurities.

TABLE 1 - Classification of Limestone[2]

CATEGORIES	PERCENTAGES	RATIOS OF CaO:MgO
Calcium Limestones*	- Calcite predominates ($CaCO_3$ crystallized in hexagonal form) - Less than 10% magnesium carbonate ($MgCO_3$)	Cao:MgO > 10.5
Magnesian Limestones	- Least common - Intermediate between other two classes - i.e. 10-40% $MgCO_3$	1.76<CaO:MgO<10.5
Dolomites	- 40-65% magnesium carbonate	1.39<CaO:MgO<1.76

* Includes "high calcium limestone" consisting of no greater than 3% total impurities and not more than 2% magnesium carbonate.

There are a great many different types of limestone, varying in colour, chemical composition, mineralogy, crystallinity, texture and hardness. There also exists other important calcium and magnesium bearing rocks and minerals such as gypsum, phosphate rock, serpentine and fluorspar which are not to be confused with limestone because they are not carbonate rocks (an essential characteristic of limestone).[1]

Virtually all limestones have been formed through sedimentation of calcareous matter deposited in layers or beds. Every bed is lens shaped. This lenticular character is typical of great limestone formations even though many lenses may be hundreds of kilometers across. During accumulation, limestone is a loose mass. Pressure and/or heat consolidate the minute carbonate particles into compact masses. The texture and crystalline form of the resulting rock depend on the size and shape of calcareous particles or grains that are deposited. Chalk is a soft, partly consolidated form of limestone; while marble is called a "metamorphic" limestone since it has been recrystallized through the agencies of heat or pressure, or both.[1,2]

Usually, deposits are contaminated with varying amounts of impurities which become part of the stone. The purest limestone formations are the thickest beds - often up to 30 m - although they may have strata of relatively impure stone. These beds are important sources for commercial uses which require relatively pure limestone such as in cement manufacture or as filler in the production of paper, ceramics or plastics.

Limestone is the most important and abundant of all sedimentary rocks. In virtually every country in the world, there is some occurrence of limestone, although in some countries its existence is largely negated by economic inaccessibility. Either it is lodged too deeply or intricately in the earth or is located in areas too distant from transportation and/or markets.[1] Next to sand and gravel, limestone is the greatest tonnage material produced in the U.S. and Canada, with a Canadian production of 62,337,933 tonnes in 1979.[3]

The quarrying and preparation of limestone depends on its intended use. Both mining and quarrying are used, although only about 5% of all limestone produced is mined. There are two kinds of quarries, shelf and open pit. [1,2]

For dimension stone, large, uniform blocks of stone are required. It is almost invariably worked from open pits. Channelling machines are used to make primary cuts for block separation. Once a key block is broken loose, horizontal holes can be drilled beneath adjoining blocks.The masses of stone removed may be 15-18 m long, 1.2 m wide and 3.0-3.7 m high. They are then subdivided into mill blocks of approximately 3.0 x 1.2 x 1.2 m and then hoisted to the surface. These blocks can be sold as is or further finished by cutting, carving, planing and polishing.[1,3,4]

The main use of limestone is as aggregate. For this purpose, a crushing operation is necessary. The rock is removed by blasting and then loaded by power shovels and hauled to the primary crusher by truck. Primary crushing may be done down in the quarry or at ground level. The type of primary crusher employed depends on the hardness and fracturing qualities of the stone, and particularly on the gradation that is desired in the primary product. For lime kiln feed, fluxstone or coarse aggregate, jaw or gyratory crushers are necessary. For use as cement kiln feed, hammer mills and other related impact crushers are preferred because they crush more finely than the other two types. Hammer mills are only practical with soft, nonabrasive stone.[1]

If a finer product is required, secondary crushing can be done by gyratory crusher when the top size of the feed is 150 mm or more. For smaller feed, cone crushers are preferred. Other secondary and tertiary crushing equipment include the hammer mill, rod mill and impact breakers.Hammer and rod mills produce the highest percentage of screening sizes, with approximately 50% in the 1000 μm to 300 μm range.[1]

Fine grinding is achieved with pebble mills and tube mills. For successful fine pulverization, the stone should be dried if necessary. Air separation may be used to remove the fine flour or dust as it is created making further comminution more effective.[1,4]

To produce filler grade limestone, either wet or dry processes may be employed. Wet grinding involves using ball and pebble mills or conical mills. The minute limestone is floated out of the mills in a suspension and removed after sedimentation and filtering. The material is then dried.[1]

Dry grinding is less costly than wet. Ball, pebble, roller and hammer mills are utilized. Closed circuit air separation and microsizer mills are employed for maximum fineness. Material can be produced with 99.5 to 100% passing a 45 μm sieve down to 1 μm, with an average particle size of 10 μm.

Vibratory screens of different types are used for sizing coarse products. The type, size and frequency of vibration is determined by the size gradation of the stone to be screened. More stringent quality requirements of the chemical and construction industries may necessitate washing of stone to reduce sand, clay and shale. By washing, the carbonate content can be beneficiated to 95-97% from deposits which have a high clay content.

Stone may be stored in stockpiles or surge piles uncovered on the ground. Enclosed silos or bins are used for finer grades of stone.[1,4]

The Canadian Industry

Limestone sources are available throughout Canada, although in some areas, such as the Prairies, it may be economically inaccessible because it is too deep or too far from transportation.[3,4] The large number of limestone producing operations in Canada preclude any detailed discussion here. A breakdown of production by province in 1980 and 1981 is shown in Table 2.

TABLE 2 - Canada, Production (Shipments) of Limestone, 1980 and 1981[3]

By Province	1980		1981	
	(000 t)	($000)	(000 t)	($000)
Newfoundland	675	1,778	338	1,223
Nova Scotia	216	1,942	213	2,088
New Brunswick	914	5,491	546	4,565
Quebec	22 987	76,533	23 155	83,221
Ontario	29 402	84,300	27 889	86,620
Manitoba	970	3,124	863	2,817
Alberta	193	991	271	2,001
British Columbia	2 834	10,926	2 503	10,611
Canada	58 191	185,085	55 778	193,146

As can be seen, the majority of Canadian limestone is produced in Quebec and Ontario. It can be found mostly along the St. Lawrence River Valley. British Columbia is the next largest producer but the amount is not nearly as significant. Very little limestone is imported: 3,257,316 tonnes in 1979, decreasing to 1,501,440 tonnes in 1982.

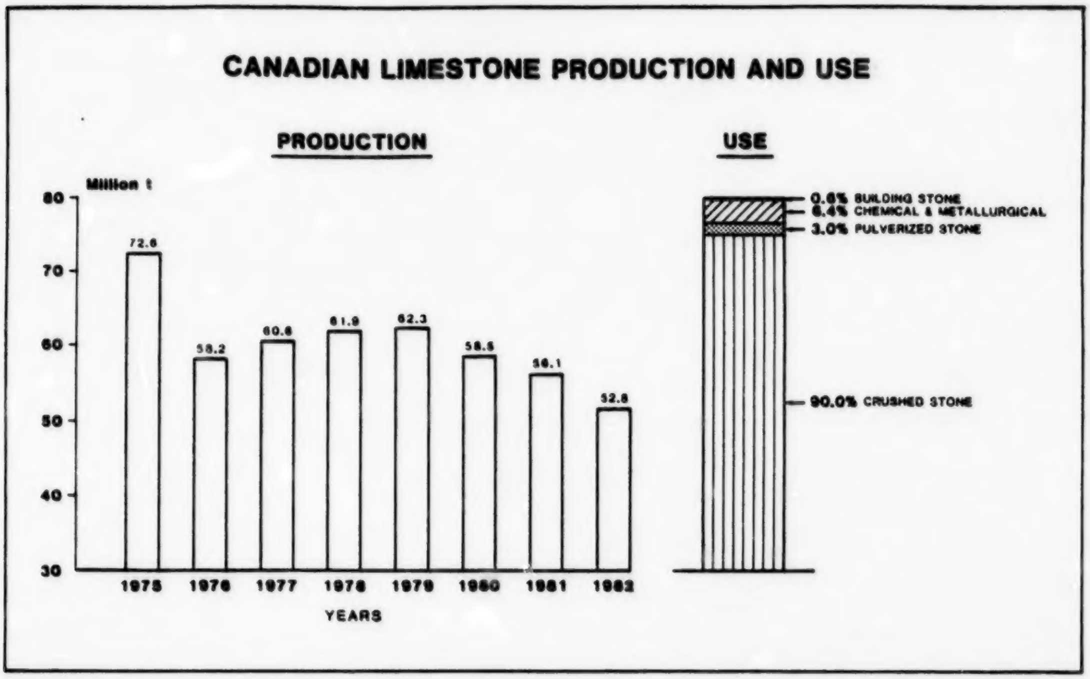
Canadian production by use can be seen in Table 3.

TABLE 3 - Canada, Shipments of Limestone by Use, 1980, 1981[3]

	1980		1981	
	(000 t)	($000)	(000 t)	($000)
Building Stone				
Rough	245	1,500	293	1,428
Monumental and ornamental	1	77	1	72
Other (flagstone, curbstone, paving blocks, etc.)	12	434	8	202
Chemical and Metallurgical				
Cement plants, foreign	1 293	2,147	1 584	2,999
Lining, open-hearth furnaces	32	90	20	71
Flux, iron and steel furnaces	1 068	3,377	757	2,779
Flux, nonferrous smelters	212	1,707	151	1,337
Glass factories	237	2,661	188	2,370
Lime kilns, foreign	306	1,102	303	1,239
Pulp and paper mills	321	2,840	345	2,886
Sugar refineries	101	394	79	378
Other chemical uses	110	1,112	148	2,277
Pulverized Stone				
Whiting substitute	32	1,513	35	1,812
Asphalt filler	53	403	34	158
Dusting, coal mines	6	159	8	167
Agricultural purposes and fertilizer plants	1 055	8,206	1 020	9,029
Other uses	573	2,749	550	466
Crushed Stone				
Artificial stone	18	50	30	123
Roofing granules	42	314	30	312
Poultry grit	52	921	24	726
Stucco dash	25	1,406	20	1,288
Rock wool	2	32	1	23
Rubble and riprap	1 048	2,190	471	1,447
Concrete aggregate	6 187	19,920	6 038	21,008
Asphalt aggregate	3 742	11,542	3 561	12,795
Road metal	19 971	59,037	18 108	58,906
Railroad ballast	992	2,322	999	3,192
Other uses	20 455	56,880	20 972	63,656
Total	58 191	185,085	55 778	193,146

The total Canadian production for 1975-1982, is shown in the following diagram.

FIGURE I - Canada, Production Volumes, 1975-82[3]
(in million tonnes, including marble)



Source: Statistics Canada; Energy, Mines and Resources Canada.

Stone is produced in direct response to the construction industry, which utilizes 95% of output, principally as crushed stone. Less than one percent of stone production is used as building stone. Chemical uses account for about 3% of stone production, the remaining 2% is consumed in pulverized form as fillers and extender materials.[3]

Market Outlook

From a tonnage standpoint, limestone's main competition is from other aggregates like sand, gravel, granite, basalt, etc., depending on cost and availability. From a usage standpoint, there are a sufficient number of overlapping uses for limestone to consider lime its most basic competition in chemical applications.[4]

In general, the outlook for limestone depends on intended use:

Dimension Stone: Traditional markets for building stone have been lost to competitive building materials such as steel and concrete. The high costs associated with quarrying, finishing, transporting and placing dimension stone in the building construction sector have contributed to the erosion of this industry.[3]

Crushed Stone: Will continue to be competitive when other sources of aggregates are scarce. It competes with gravel as railway ballast and road metal, and as aggregate in concrete and asphalt depending on cost and availability.[3]

Chemical/Metallurgical Applications & Fillers: These applications make up only a small portion of the total market for limestone, approximately 5% of total production. Limestone is used in cement and lime manufacture and as fluxing material in the metallurgical industry. The market for limestone as a filler is expanding. This is due both to changes in manufacturing processes creating a demand for $CaCO_3$, and to improved technology available to all major producers, making them able to offer a "superfine" grade of calcium carbonate fillers for uses in the manufacture of paper, plastics and paints. These superfine grades offer significant advantages over competing fillers such as excellent brightness, low abrasiveness, ease of dispersion, and in some cases, lower costs.[1,3,5]

Limestone is a rock of which the basic constituent is calcium carbonate ($CaCO_3$) or a double carbonate of calcium and magnesium. The approximate composition of several samples of limestone are shown in Table 4.

TABLE 4 - Typical Composition of Canadian Limestones

COMPONENT	LIMESTONE SAMPLE (%)			
	1	2	3	4
SiO_2	6.4	0.64	1.43	0.48
Fe_2O_3	0.58	0.18	0.72	0.51
Al_2O_3	1.68	0.21	0.66	0.27
$Ca_3(PO_4)_2$	0.07	0.15	0.04	0.02
$CaCO_3$	88.68	98.05	71.75	55.55
$MgCO_3$	1.18	0.97	25.22	42.87
Total	98.59	100.20	99.82	99.70
S	0.23	0.05	0.19	0.01
CaO	49.70	54.99	40.20	31.12
MgO	0.56	0.46	12.06	20.50
Ratio CaO:MgO	89:1	120:1	3.3:1	1.52:1
Classification	High Calcium	High Calcium	Magnesian	Dolomitic

NOTES:

1. High calcium limestone, Cape Breton, N.S.
2. High Calcium limestone, Joliette, Que.
3. Magnesian limestone, Lincoln County, Ont.
4. Dolomitic limestone, Halton County, Ont.

Source: M.F. Goudge, "Limestone of Canada"[2]

Limestones range in colour from pure white through grey and black, from blue through green, and from yellow to orange, to red and brown. These various colours are due to the presence of small quantities of pigmented impurities. Limestones free of these impurities are white.[1,4]

The texture of limestone varies considerably. Some limestones are compact, others are porous and full of cavities. All limestones are crystalline. Even chalk, which appears amorphous, is actually composed of minute crystals of $CaCO_3$ visible only under a microscope.[1,2]

Limestones also have a wide range in hardness. The amount and character of the cementing material, as well as the degree of cementation, have a great effect on hardness. The common cementing materials in limestone are silica, calcium carbonate and dolomite.[2,4] A few of the other relevant physical properties of limestone are shown in Table 5.

TABLE 5 - Properties of Limestone[1]

Specific Gravity	2.7
Hardness (Mohs scale)	3
Refractive Index	1.63 - 1.66
pH	7.8 - 8.5
Oil Absorption (cc/100gm)	12 - 30

No limestone deposit is free from impurities, the most common of which are silica, alumina, iron compounds, sulphur, alkalies, organic matter and phosphorous. They may be present in very small quantities, or constitute a large percentage of a deposit. Table 6 gives more details.

TABLE 6 - Principal Minerals & Impurities of Limestone[1,2,4]

MINERAL OR IMPURITY	PROPERTIES
Calcite $CaCO_3$	- Essential constituent - Crystals of all shapes - Effervescent when dilute acid placed on it
Dolomite $CaMg(CO_3)_2$	- Distinguish from calcite by faint or lack of reaction to cold acid - Hot acid results in brisk effervescence - Present to some extent in all limestones
Silica SiO_2	- Present in all limestones, from traces to large quantities - Forms: sand grains, chert nodules, quartz veins
Alumina Al_2O_3	- Present in combination with silica as shale or argillaceous matter (clay) - From traces to large quantities
Iron Commonly as Fe_2O_3	- Primarily in the form of oxides & sulfides - Oxides impart various colours to limestone - Ferrous iron is particularly characteristic of dolomites
Sulphur Commonly with iron as FeS_2	- Occurs principally in combination with iron as either pyrite or marcasite - H_2S (hydrogen sulphide may be occluded in the stone)
Organic Matter	- Vegetable (carbonaceous) matter deposited in the limestone as it was formed - black pigment
Others	- Phosphorus - small amounts in all Canadian deposits; Alkalies Na_2O or K_2O

Quality criteria for limestone vary with intended use (see Table 7). The chemical composition of any sample does vary from the theoretical. This is not necessarily a disadvantage. Particle characteristics may also vary depending on the raw material and methods of processing. Some minerals are prepared in a wide range of different grades, which are patterned to meet specific consumer requirements. Particle shape and surface characteristics are dependent somewhat on the fineness and method of preparation, but are mostly inherent characteristics of the rock itself. Properties such as specific gravity, refractive index, hardness and thermal properties can be modified little if at all by milling but heat treatments may alter such properties to an important extent.[1,4]

Many tests can be made at the specific request of consumers to meet particular needs such as: absorption, porosity, crystal structure, bulk density, hardness, strength, thermal conductivity, refractive index, electrical resistivity, solubility, pH, reaction with acids, etc.

The predominant chemical property of limestone is that it can be thermally decomposed (calcined) into lime. All carbonate rocks dissociate at high temperature, forming oxides of calcium and magnesium through expulsion of CO_2 gas.

TABLE 7 - Quality Criteria for Some Uses of Limestone[1,4]

USE	PROPERTIES OF INTEREST
Building Stone	- Size, shape, colour, grain - Other aesthetic qualities
Crushed Stone	- Same physical and chemical testing procedures as sand and gravel.
Aggregate	- Concrete aggregates must not contain chert (SiO_2) nodules.
Pulverized Stone	
Agricultural	- High calcium or magnesium, basic pH (7.0); used to control soil acidity.
Filler-general	- 150-45 μm particle size down to low μm range; hygroscopicity, colour, purity and surface characteristics are important; low abrasiveness.
Paper	- Brightness, low abrasiveness, ease of dispersion; coatings 1 μm, filler grades 1-2.5 μm
Plastics	- finer fillers with modified size distribution, oil absorption, low abrasiveness.
Paints	- superfine grades (as pigment extender)
Chemical/ Metallurgical	
Lime	- High calcium (95%)
Glass	- High calcium or magnesium, uniform stone, low iron, phosphorous and sulphur
Sugar	- Only high calcium stone (97%), no impurities; to precipitate impurities
Cement	- Low magnesium (2%); high silica, aluminum and calcium, some iron
Flux	- Combines with impurities to form fluid slag (in basic processes) - Low silica, high calcium - No magnesium for open hearth method - Either calcium or dolomitic limestone for blast furnaces
Others	- Uses include: manufacture of soda ash, calcium carbide, calcium nitrate, carbon dioxide, pharmaceuticals, disinfectant, dyes, rayon; neutralization of acid waste and many more.

Limestone is used extensively as a filler or extender and, where quality permits, as whiting. In such applications, both physical and chemical properties are important. Specifications vary widely but, in general, a uniform white material passing 45 µm would meet the physical requirements. Whiting is used in ceramic bodies, plastics, paper, insecticides, rubber, paints and as a filler in other commodities. In paint manufacture, the material may be used as pigment extender. Fillers are employed to modify chemical, physical, thermal or optical properties or composition. The ultimate selection of a filler for a particular application frequently depends on cost, availability and contemporary practices or traditions.[1,3,4,5]

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REFERENCES

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